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Management of Hybrid Bluegrass (*Poa arachnifera* Torr. x *Poa pratensis* L.) in the Transition Zone

Travis Charles Teuton
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To the Graduate Council:

I am submitting herewith a dissertation written by Travis Charles Teuton entitled "Management of Hybrid Bluegrass (*Poa arachnifera* Torr. x *Poa pratensis* L.) in the Transition Zone." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Plants, Soils, and Insects.

Thomas C. Mueller, Major Professor

We have read this dissertation and recommend its acceptance:

John C. Sorochan, Carl E. Sams, Thomas J. Samples, William E. Hart

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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(Original signatures are on file with the official student records.)

MANAGEMENT OF HYBRID BLUEGRASS (*Poa arachnifera* Torr. x *Poa pratensis* L.) IN THE TRANSITION ZONE

A Dissertation
Presented for the
Doctor of Philosophy
Degree
The University of Tennessee

Travis Charles Teuton
May 2006

DEDICATION

I dedicate my dissertation to my wife Jennifer and my children Dakota and Cory. They are the joy of my life and the drive that keeps me going everyday. I think Robert Frost sums up my life the best in the *Road Not Taken* and this excerpt shows the path to my existence:

"I shall be telling this with a sigh
Somewhere ages and ages hence:
Two roads diverged in a wood, and I-
I took the one less traveled by,
And that has made all of the difference."
-Robert Frost (1915)

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I also give special thanks to Dr. Christopher Main for his guidance, commitment to excellence, and most of all being a great friend. In addition I wish to acknowledge Johnny Parham, Joe Beeler, Matt Goddard, Jake Godsey, Dan Strunk, and Jenny Clement for their assistance. They made this research possible and their fellowship made my time at the University of Tennessee enjoyable.

To God, by whose grace all things are possible.

ABSTRACT

Dura Blue™ and Thermal Blue™ hybrid bluegrass (*Poa arachnifera* Torr. x *Poa pratensis* L.) have been selected for increased heat and drought tolerance and offer an alternative to traditional Kentucky bluegrass and tall fescue in the transition zone. Dura Blue and Thermal Blue were compared to Apollo™ Kentucky bluegrass, Dynasty™ tall fescue, and Kentucky 31 tall fescue. All turfgrass species tested were acceptable for use in the transition zone. Thermal Blue should be seeded from 50 to 150 kg seed/ha. Thermal Blue should be seeded in September for highest quality and most rapid turf cover. However, January and April provided complete turf cover 7 months after seeding. Thermal Blue should be fertilized with 100 to 300 kg N/ha/yr. However, higher nitrogen fertility reduced turf quality in late summer and early fall. Thermal blue can be mowed at heights from 20 to 50 mm, although, mowing heights should be ≥ 35 mm to avoid decreased turf quality in the late summer and fall. Applications of the plant growth regulators ethephon and paclobutrazol caused injury to Thermal Blue during the summer and should be avoided. Thermal Blue exhibited a significant reduction in cover (>57%) from dithiopyr, oryzalin, oxadiazon, pendimethalin, prodiamine, quinclorac, and trifluralin applied at turf seeding. Postemergence applications of foramsulfuron and trifloxysulfuron on established Thermal Blue decreased turf quality and caused unacceptable injury (>15%). Established Thermal Blue treated with clethodim, fluazifop-p-butyl, and sethoxydim showed decreased quality and unacceptable injury (>15%). Hybrid bluegrass is thought to have increased heat tolerance based on greater total nonstructural carbohydrate (TNC) accumulation. Thermal Blue hybrid bluegrass, Apollo

Kentucky bluegrass, Supranova™ supina bluegrass, and Laser™ rough bluegrass showed linear decreases in TNC accumulation in the leaves from April to July. However, hybrid bluegrass and Kentucky bluegrass showed a linear increase in TNC accumulation in the roots from April to July. This research indicated that hybrid bluegrass and Kentucky bluegrass may have more heat tolerance due to a reallocation of TNC from the leaves in April to the roots in July.

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PART I

INTRODUCTION

Growing quality turfgrass throughout the year in the transition zone is difficult. The transition zone, indicating an area of transition from cool to warm-season turfgrasses, is the area between the cool and warm regions of the world (Beard 1973). Traditionally the main turfgrasses grown in the transition zone are zoysiagrass (*Zoysia japonica* Steud.), bermudagrass [*Cynodon dactylon* (L.) Pers.], ryegrass (*Lolium spp.*), bentgrass (*Agrostis spp.*), Kentucky bluegrass (*Poa pratensis* L.), and tall fescue (*Festuca arundinacea* Schreb.) (Beard 1973). Zoysiagrass and bermudagrass can successfully be grown in the transition zone; however, winter dormancy and occasional winter kill cause unsightly appearances in the winter and early spring (Munshaw et al. 2004). Likewise, Kentucky bluegrass and tall fescue can be grown in the transition zone, but high humidity and high temperatures associated with summer and droughty soil conditions are often too stressful for Kentucky bluegrass and tall fescue to thrive under these conditions. Diseases such as rust (*Puccinia graminis* Pers. subsp. *graminicola* Urban) and dollar spot (*Sclerotinia homoeocarpa* Bennett) occur in Kentucky bluegrass and brown patch [*Rhizoctonia solani* (Kühn)] occurs in tall fescue under these stressful conditions (Wang and Huang 2004, Landshchoot and Park 1997).

Hybrid bluegrass (*Poa arachnifera* Torr. x *P. pratensis* L.) is an alternative to bermudagrass, zoysiagrass, Kentucky bluegrass, and tall fescue. Dura Blue and Thermal Blue[1] for commercial use. Traditionally, Kentucky bluegrass has not been the turfgrass variety of choice in the southern part of the transition zone because of its lack of heat,

[1] The Scotts Company, 14111 Scottslawn Rd., Maryville, OH 43041

drought, and disease tolerance. Hybrid bluegrass has displayed the heat and drought tolerance of Texas bluegrass (*P. arachnifera* Torr.) and the desirable turfgrass quality and color of Kentucky bluegrass (Abraham et al. 2004). However, the same diseases (leaf spot, leaf rust, dollar spot, etc.) are still of concern with the hybrid bluegrass. The susceptibility and severity of these diseases are not known.

Kentucky bluegrass is widely utilized in the transition zone and in the colder northern climates where previous research has established seeding rates, nitrogen fertility, and mowing heights are used (Beard 1973, Bredakis 1959, Jagschitz and Skogley 1965, Juska et al. 1955, Juska and Hanson 1961, Kuhn and Kemp 1939, Skogley and Ledeborer 1968). In general, Kentucky bluegrass should be seeded between 50 to 100 kg/ha which produces 3 to 8 seed per cm^2 (Beard 1973). However, turfgrass breeders and developers have had problems with low seed yield, low germination rates, and poor seedling vigor in many of the new hybrid varieties (Jim Frelich, personal communication).

Plant growth regulators (PGR) are frequently used in turf to decrease clipping yield, improve turf quality, and inhibit seedhead production (Watcshke et al. 1992). Trinexapac-ethyl and paclobutrazol inhibit gibberellic acid (GA) production within the plant and are used to enhance turfgrass color, quality, and decrease clipping yields (Ervin and Koski 2001, Lickfeldt et al 2001, Rademacher 2000, Steinke and Stier 2003). Trinexapac-ethyl also has been shown to decrease the incidence of the foliar disease dollar spot (Lickfelt et al. 2001). However, trinexapac-ethyl decreases heat tolerance of turf by reducing cell membrane stability in Kentucky bluegrass during heat stress (Heckman et al. 2002). Also, trinexapac-ethyl does not inhibit seed-head production like paclobutrazol due to a different site of action during GA synthesis (McCullough 2005, Rademacher 2000). Paclobutrazol inhibits GA early during synthesis whereas trinexapac-ethyl inhibits GA during late synthesis (Rademacher 2000). Paclobutrazol is commonly used for annual bluegrass (*Poa annua* L.) suppression in creeping bentgrass (*Agrostis stolonifera* L.) greens (Woosley et al. 2003). Paclobutrazol also decreases the incidence of the foliar disease dollar spot and can reduce turfgrass color and quality during summer heat stress conditions ((Burpee et al. 1996, Symington et al. 1986).

Ethephon is common plant growth regulator used in turf. Ethephon decomposes to release ethylene. Plants naturally release ethylene when they are injured or during times of stress which causes growth inhibition (Taiz and Zeiger 2002). Turf discoloration from exogenous applications of ethylene is common in both warm- and cool-season grasses. Ethephon has been shown to cause injury in warm-season grasses (Shatters 1998). However, no long-term adverse effects have been shown from ethephon applications to Kentucky bluegrass (Christians 1985, Christians and Nau 1984, Diesburg and Christians 1989).

Weed control is essential to maintaining a high quality turfgrass. Busey (2003) reported that increasing nitrogen fertility increases the quality and competitiveness of the turfgrasses which decreases the invasion of crabgrass (*Digitaria spp.*) and dandelion (*Taraxacum officinale* Weber), although herbicides may be needed to achieve complete weed control. Dithiopyr has shown excellent crabgrass control and no Kentucky bluegrass injury when applied at least 3 d after emergence (DAE) of Kentucky bluegrass seedlings (Reicher et al. 2000). Other research has also shown tolerance of mature

Kentucky bluegrass to dithiopyr at 400 to 1100 g ai/ha (Bhowmik and O'Toole 1993; Neal 1990; Prostak and Ilnicki 1993). However, other dinitroanaline herbicides such as pendimethalin, prodiamine, and oryzalin have shown potential to reduce Kentucky bluegrass rooting (Prostak and Ilnicki 1993).

Single applications of chlorosulfuron or metsulfuron controlled tall fescue 90% in Kentucky bluegrass stands. However, both resulted in Kentucky bluegrass injury during drought stress the following summer when compared to the untreated control (Dernoeden 1990). Applications of quinclorac injured Kentucky bluegrass when applied at 600 g ai/ha 28 DAE and at 1100 g ai/ha 28, 56, and 84 DAE (Neal 1990). Lycan et al. (2001) reported 39 and 76 % reduction in Kentucky bluegrass coverage 30 d after treatment (DAT) when applying quinclorac at 600 and 1300 g ai/ha.

The optimal growing temperature range (air) for shoot growth of cool-season turfgrass is 16-24 C (Beard 1973), however temperatures in the transition zone often approach 30 C or higher during the summer months. Nonstructural carbohydrates are an important energy reserve used by plants to survive stress conditions (Watschke et al. 1972, 1973; Beard 1973; Howard and Watschke 1985, 1991; Hull 1992). Several studies in growth chambers have found that increasing temperatures decrease carbohydrate availability (Al-Khatib and Paulsen 1989; Moffat et al. 1990; Liu and Huang 2000; Xu and Huang 2000a, 200b; Liu and Huang 2001). Reductions in photosynthetic rate, chlorophyll content, carbohydrate accumulation, and cell membrane stability due to heat stress have been observed in creeping bentgrass, Kentucky bluegrass, and perennial ryegrass (Wehner and Watschke 1984; White et al. 1998; Howard and Watschke 1991;

Huang et al. 1998). Previous research has reported that roots were more sensitive to heat stress than shoots (Xu and Huang 2000a, 2000b). In creeping bentgrass, decreased carbohydrates are associated with decreased root growth, tiller production, shoot growth and overall plant health (Carrow 1996; Xu and Huang 2000 a, 2000b, 2001; Sweeney et al. 2001).

Turfgrasses accumulate total nonstructural carbohydrates (TNC) as the monosaccharides glucose and fructose, the disaccharide sucrose, and various oligosaccharides, starches, and fructans (Smith 1972). Aldous and Kaufmann (1979) observed root death in Kentucky bluegrass at high temperatures resulting in a decline in shoot growth. This decline was suggested to be from reductions in carbohydrate content in the roots. In creeping bentgrass, mid-summer reductions in TNC in shoot and roots were related and proportional to the reduction of sugars and fructans (Xu and Huang 2003). The decline in carbohydrates during mid summer is due to decreased photosynthesis and increased dark respiration (Carrow 1996; Huang and Gao 2000; Xu and Huang 2000b; Liu an Huang 2001). Watsche et al. (1972) reported a 47% reduction in photosynthesis, and a 36% reduction of TNC when cool-season grasses (*P. pratensis*, *P. trivialis* L., *P. compressa* L., and *Lolium perenne* L.) were placed in excessively high temperatures.

A literature search of hybrid bluegrass revealed no published data on management practices in the transition zone or heat tolerance mechanisms over other bluegrass species. Therefore, the objectives of our experiments were to: 1) compare hybrid bluegrass to other commonly grown grasses in the transition zone, 2) determine optimum seeding rates, timing of seed application, and mowing heights, 3) determine its tolerance to commonly use plant growth regulator and herbicides, and 4) determine if non-structural carbohydrates play a role in increased heat tolerance of hybrid bluegrass.

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PART II

HYBRID BLUEGRASS, KENTUCKY BLUEGRASS, AND TALL FESCUE RESPONSE TO NITROGEN FERTILIZATION IN THE TRANSITION ZONE.

This chapter will be submitted for publication in the journal HortScience. My primary contributions to this paper include selection of the topic, most of the maintenance, part of the data collection, most of the literature search, and most of the writing.

ABSTRACT

Dura Blue™ and Thermal Blue™ hybrid bluegrass have been selected for heat and drought tolerance. These grasses offer an alternative to traditional Kentucky bluegrass and tall fescue in the transition zone. Experiments were conducted in two locations during 2003 and 2004 at the University of Tennessee in Knoxville, Tenn. Nitrogen (N) was applied at 50, 150, and 300 kg N/ha/yr to 'Apollo™' Kentucky bluegrass, 'Dura Blue', and 'Thermal Blue' hybrid bluegrass, and 'Dynasty™' and 'Kentucky 31' tall fescue. Regression analysis indicated good turfgrass color for Apollo, Dura Blue, Dynasty, and Thermal Blue (6.7 to 7.4) from March thru November at 50, 150, and 300 kg N. Kentucky 31 had a paler green, less desirable color. All bluegrass varieties were below the minimum 6.5 quality evaluation when treated with 50 kg N. However, applying 150 and 300 kg N from March thru November improved bluegrass colors to > 6.7. Quality observations for Dynasty and Kentucky 31 were acceptable (6.6-7.1) during the growing season. Dry tissue weights were highest within each nitrogen fertility level for Kentucky 31 and Thermal Blue. No significant differences in brown patch incidence were observed at each nitrogen level between Dynasty and Kentucky 31. However significant increases in brown patch incidence occurred as N levels decreased from 300 kg N (21%) to 50 kg N (31%). Dollar spot incidence occurred on all bluegrass varieties

from 7 to 24% with Thermal blue showing the highest level of incidence. However, dollar spot decreased with increased N fertility. All turfgrass species tested were acceptable for use in the transition zone with Apollo Kentucky bluegrass and Dura Blue hybrid bluegrass being the most desirable.

Nomenclature: hybrid bluegrass (*P. arachnifera* Torr. x *P. pratensis* L.) 'Thermal Blue' and 'Dura Blue'; Kentucky bluegrass (*Poa pratensis* L.) 'Apollo'; tall fescue (*Festuca arundinacea* Schreb.) 'Dynasty' and 'Kentucky 31'.

Additional Index Words: transition zone, fertility, dollar spot, brown patch.

Abbreviations: MAS, months after seeding

INTRODUCTION

Growing quality turfgrass throughout the year in the transition zone is difficult. The transition zone, indicating an area of transition from cool to warm-season turfgrasses, is the area between the cool and warm regions of the world (Beard 1973). Traditionally the main turfgrasses grown in the transition zone are zoysiagrass (Zoysia japonica Steud.), bermudagrass [*Cynodon dactylon* (L.) Pers.], ryegrass (*Lolium* spp.), bentgrass (*Agrostis* spp.), Kentucky bluegrass (*Poa pratensis* L.), and tall fescue (*Festuca arundinacea* Schreb.) (Beard 1973). Zoysiagrass and bermudagrass can successfully be grown in the transition zone; however, winter dormancy and occasional winter kill cause unsightly appearances in the winter and early spring (Munshaw et al. 2004). Likewise, Kentucky bluegrass and tall fescue can be grown in the transition zone, but high humidity and high temperatures associated with summer and droughty soil conditions are often too stressful for Kentucky bluegrass and tall fescue to thrive under these conditions. Diseases such as rust (*Puccinia graminis* Persoon subsp. *graminicola* Urban) and dollar spot (*Sclerotinia homoeocarpa* Bennett) occur in Kentucky bluegrass and brown patch [*Rhizoctonia solani* (Kühn)] occurs in tall fescue under these stressful conditions (Wang and Huang 2004, Landshchoot and Park 1997).

Alternatives to bermudagrass, zoysiagrass, Kentucky bluegrass, and tall fescue are new hybrid bluegrass (*Poa arachnifera* Torr. x *P. pratensis* L.) (Registered with the USDA as Kentucky bluegrass varieties however, for the ease of discussion they will be call hybrid bluegrass). Two varieties, Dura Blue and Thermal Blue, have recently been released by The Scotts Company[2] for commercial use. Traditionally, Kentucky bluegrass has not been the turfgrass variety of choice in the southern part of the transition zone because of its lack of heat, drought, and disease tolerance. Hybrid bluegrass has displayed the heat and drought tolerance of Texas bluegrass (*P. arachnifera* Torr.) and the desirable turfgrass quality and color of Kentucky bluegrass (Abraham et al. 2004). However, the same diseases (leaf spot, leaf rust, dollar spot, etc.) are still of concern with the hybrid bluegrass. The extent of the susceptibility these diseases are not known.

Kentucky bluegrass fertility and management is different than that of tall fescue. Kentucky bluegrass fertilization ranges from 19 to 64 kg N/ha/month depending on variety (Beard 1973). Kentucky bluegrass may have increased incidence of dollar spot and leaf rust when managed with low nitrogen fertility levels. Tall fescue fertilization

[2] The Scotts Company, 14111 Scottslawn Rd., Maryville, OH 43041

ranges from 19 to 50 kg N/ha/month (Beard 1973). However, the disease brown patch is a problem of tall fescue during summer heat stress, and increased levels of brown patch may occur with excess N fertilization (Christians 1998).

One consideration with the introduction of new turfgrass varieties such as Dura Blue and Thermal Blue is determining whether these varieties are better suited for establishment and use than traditional species. The objectives of this experiment were to determine if fertility levels affected color, quality, clipping yield, and disease incidence of Apollo Kentucky bluegrass, Dura Blue and Thermal Blue hybrid bluegrass, and Dynasty and Kentucky 31 tall fescue.

MATERIALS AND METHODS

Field experiments were conducted to determine the effect of nitrogen fertilization on the color, quality, and clipping yield of aforementioned turfgrass cultivars. Turfgrasses were seeded on 23 October 2002 at the Horticultural Trial Gardens (Campus location) and on 26 September 2003 at the Plant Science Farm (PSF location) at the University of Tennessee in Knoxville, Tennessee. The soil at the Campus location was an Etowah silt loam (typic Paleudalt fine, loamy, siliceous thermic) and the soil at the PSF was a Sequatchie loam (fine-loamy, siliceous, thermic Humic Hapudult). Kentucky bluegrass and tall fescue varieties were seeded at 100 and 300 kg/ha respectively, with Apollo, Dura Blue, Thermal Blue, Dynasty, and Kentucky 31 having 3200, 1500, 2500, 420, and 440 thousand seeds per kg, respectively. Turfgrasses were fertilized at the time of seeding and monthly thereafter until December with 24 kg N/ha to insure adequate turfgrass density. Treatment regimes started in April of each yr included 50, 150, and

300 kg N/ha/yr. The 50 kg N treatment was applied as 24.5 kg N in April and September. The 150 kg N treatment was applied as 24.5 kg N in April and May and 50 kg N in September and December The 250 kg N treatment was applied as 50 kg N in April, May, June, July, September, and December The April fertilization for all treatments was an 18N-0P-8.3K analysis fertilizer with dithiopyr [S,S-dimethyl 2-(difluoromethyl)-4-(2-methylpropyl)-6-(trifluoromethyl)-3,5-pyridinedicarbohthioate] for preemergence crabgrass control. All other nitrogen treatments were derived from a commercial fertilizer with a 29N-1.3P-3.3K analysis. Soil tests were performed at both locations. Phosphorus and potassium were not limiting, therefore all assumptions on turfgrass growth were made based on nitrogen. Turfgrasses were mowed weekly at 7.5 cm at both locations. Plots were watered at both locations to insure adequate germination and establishment. After establishment subsequent water was applied at both locations as needed.

Visual observations of color and quality were recorded monthly. Color was visually evaluated on a scale of 1-9, with 1 being brown turfgrass and 9 being the darkest green turfgrass. Quality was based on color, density, uniformity, texture, and disease incidence or environmental stress effect. Quality was visually evaluated on a scale of 1 to 9, with 1 being brown or dead turfgrass and 9 being ideal turfgrass (Skogley and Sawyer 1992). A quality standard of 6.5 was the minimum acceptable turfgrass quality level. Turfgrass clippings were collected monthly from March thru December for both locations, and dry weights were recorded following 4 d of forced air drying at 65 C. Brown patch and dollar spot incidence were monitored and data were recorded monthly from the first visual symptoms until the disease incidence was gone. Brown patch and dollar spot were visually estimated on a 0-100% scale, with 0% being no dollar spot and 100% equaling dead turf.

SAS (1999) Proc Mixed was utilized to perform analysis of variance for turfgrass color, quality, clipping yield, brown patch, and dollar spot. All data were normally distributed with equal variance (Shapiro-Wilk >0.90) and arcsine square root transformations were not performed. Main effects and all possible interactions were tested using appropriate expected mean square values as recommended by McIntosh (1983). Nitrogen regimes, sampling interval, and turfgrass species were highly significant ($p<0.0001$) for color and quality. However, there was no effect ($p>0.05$) of location, trial, year, or their interactions. Therefore, color and quality data were pooled across studies and regression analysis were performed. Dry weight data analysis indicated that nitrogen regime, turfgrass species, and their interaction were highly significant ($p<0.0001$). There was no effect ($p>0.05$) of time, location, trial, year, or their interactions. Therefore, dry weight data were pooled across studies and means were separated using Fisher's Protected LSD at the 5% significance level. Nitrogen regimes, turfgrass species, and nitrogen*turfgrass interaction were highly significant ($p<0.0001$) for brown patch and dollar spot. However, there was no effect ($p>0.05$) of sampling interval, location, year, or their interactions. Therefore, brown patch and dollar spot data were pooled across studies and means were separated using Fisher's Protected LSD at the 5% significance level.

The color and quality evaluations for each location were regressed using Sigma Plot (Systat Software, Point Richmond, CA 94804-2028). Turfgrass color and quality were regressed against time using a logistic model (Eq. [1]) as suggested by Thornley and Johnson (1990):

$$y = a/(1+\exp(-(\text{Month}-c)/b)) \qquad \text{Eq. [1]}$$

where, (a) is the asymptote of total color or quality, (c) describes the amount of time to reach the inflection point for maximum color or quality and (b) is an estimate of the duration of time to reach a constant color or quality value.

RESULTS AND DISCUSSION

Regression analysis of color revealed a good fit ($r^2>0.88$) for all color evaluations, using a logistic model (Figure 1[3]). Regression analysis for turfgrass quality ranged from r^2 of 0.63 to 0.84 (Figure 2). However, after careful evaluation of the quality data it was evident the decreased fit of the logistic model was due to the decreased density and decreased aesthetic value in March. The lower March values were due to the harsher temperatures of January and February, which the turfgrasses were overcoming in March. However, the logistic model was still appropriate for quality and all assumptions on color and quality were made based on the logistic model.

All bluegrass varieties displayed excellent color through the growing months of March to December (Figure 1). Apollo, Dura Blue, and Thermal Blue color ranges were from 6.7 to 7.4 for all nitrogen regimes. Dura Blue maintained the highest color

[3] All tables and figures are located in the appendices.

evaluations for all nitrogen regimes and Thermal Blue displayed the lowest color evaluations. Dynasty showed little difference in color (7.1 to 7.4) when compared to the bluegrass varieties during the growing season. However, Kentucky 31 exhibited a lower color value, ranging from 6.4 to 6.6 for all nitrogen levels during the growing season due to an overall pale green appearance for this variety. All grasses exhibited poor color during January and February due to cold temperatures.

All turfgrasses responded well to increased nitrogen except Kentucky 31, where minor color differences were observed. Each bluegrass variety displayed a good color response from 50 to 150 and 50 to 300 kg N. Also, tall fescue varieties showed an increased color response from 50 to 150 kg N, although there was little response from 150 to 300 kg N. This indicates that the ideal amount of N for tall fescue is 150 kg N/ha/yr and from 150 to 300 kg N/ha/yr for the bluegrass varieties. The greatest color response based on the asymptote of total color (variable "a" in the logistic model) was with Apollo (0.80), then Thermal Blue (0.57), Dura Blue and Dynasty at (0.35), and Kentucky 31 having a negligible color increase (0.14).

Apollo, Dura Blue, and Thermal Blue showed increased quality as nitrogen levels increased. All bluegrass varieties were below the minimum 6.5 quality evaluation at 50 kg N. However, quality for all bluegrass varieties ranged from 6.7 to 7.1 at the 150 and 300 kg N from March thru November. Both Dynasty and Kentucky 31 quality were above the minimum of 6.5 from March thru November. Quality observations for Dynasty were higher than bluegrass varieties tested, however all quality observations were predicted to range from 6.6 to 7.1 during the growing season. Dynasty and Kentucky 31 did not display improved quality with increasing nitrogen fertility.

The greatest quality response based on the asymptote of total color (variable “a” in the logistic model Eq. [1]) was with Apollo (0.90), then Dura Blue and Thermal Blue (0.66 and 0.61), Kentucky 31 (0.48), and Dynasty having a negligible quality increase (0.33). This indicates that the Apollo, Dura Blue, and Thermal Blue have an increased quality response to additional N fertilization when compared to tall fescue, and may be better suited for higher input maintenance practices.

Actual quality evaluations in March were lower for all turfgrass varieties, as discussed earlier. This is due to the cold winter temperatures of January and February where all turfgrasses were below the minimum 6.5 quality level. However, both tall fescue varieties had higher quality evaluations (>5.9) for all nitrogen rates than the bluegrass varieties during March. This indicates that Dynasty and Kentucky 31 both recover from dormancy before the bluegrass varieties tested. However, December nitrogen applications to the 150 and 300 kg N improved the quality of the Apollo, Dura Blue, and Thermal Blue as compared to the tall fescue varieties. This is consistent with Miltner et al. (2004) who saw increases in turfgrass quality with November and December soluble nitrogen applications.

Dry weights increased with increased nitrogen for all turfgrasses (Figure 3). Kentucky 31 had the largest biomass production for each nitrogen level, followed by Thermal Blue which was the second highest biomass producer when treated with 150 and 300 kg N. Thermal Blue was not different from Dura Blue or Dynasty at 50 kg of N.

There were no differences in biomass for Apollo, Dura Blue, and Dynasty at 150 and 300 kg N. However at 50 kg N, Apollo had a lower dry weight than the other turfgrasses. Previous research indicates that nitrogen use and efficiency will be increased by returning clippings to the soil and nitrogen requirements may be decreased as much as half after the first year if clippings are returned (Kopp and Guillard 2002). Also, increasing nitrogen increases the quality of the turfgrasses by decreasing invasion of species like crabgrass (*Digitaria spp.*) and dandelion (*Taraxacum officinale* Weber) (Busey 2003).

No differences occurred for brown patch incidence between tall fescue varieties at any nitrogen level. Brown patch incidence from May to August decreased 9% in Dynasty when N increased from 50 to 150 kg (Table 1). However, there was no difference from 50 to 150 kg N for Kentucky 31. Brown patch incidence was reduced in Dynasty and Kentucky 31 at 50 to 300 kg N. This was similar to a previous study conducted on perennial ryegrass (*Lolium perenne* L.) where 40 kg N/ha decreased brown patch over 0, 100, and 200 kg N/ha (Watkins et al. 2001). On the other hand, Vincelli et al. (1997) reported increasing brown patch on tall fescue with increasing nitrogen from 50 to 196 kg N one year and no differences in brown patch severity the next.

All bluegrass varieties tested exhibited more dollar spot with decreased N. Thermal Blue and Dura Blue showed reduced dollar spot incidence from 50 to 150 kg N. Thermal Blue also tended to exhibit the highest dollar spot incidence at each nitrogen level. Dollar spot incidence was less prevalent at higher N treatments for all bluegrass varieties (Table 1). This is consistent with Golembiewski and Danneberger (1998) who observed decreases in dollar spot on creeping bentgrass (*Agrostis stolonifera* L.) with increased N fertilization.

In summary, there were few differences in color and quality for Apollo, Dura Blue, and Dynasty. Thermal Blue and Kentucky 31 had similar quality evaluations to Apollo, Dura Blue, and Dynasty, however, both Thermal Blue and Kentucky 31 displayed less desirable color. Both Kentucky 31 and Thermal Blue produced more biomass than the other turfgrasses. There was little difference in brown patch severity in tall fescue varieties. Apollo, Dura Blue, and Thermal Blue all had about the same incidence of dollar spot.

Based on these observations all turfgrasses tested would make suitable turfgrasses for the transition-zone homeowner. However, Apollo and Dura Blue have the darkest color, least disease pressure, and would be the most desirable choices and they should be fertilized between 150 and 300 kg N per year. Thermal Blue had good color and quality, although, excessive clipping production were problems. Dynasty and Kentucky 31 require less nitrogen and would be desirable in a reduced maintenance situation. However, both tall fescue varieties are susceptible to brown patch regardless of N rate. If a finer texture turfgrass is required, Kentucky 31 would not be a favorable choice. All of the bluegrass varieties should only be used in high maintenance situations such as golf courses, sports fields, or high maintenance home-lawns in the transition zone. Apollo, Dura Blue, or Thermal Blue or possibly blends of the three species would produce a high quality turfgrass, however further research is needed to investigate the performance of these blends.

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PART III

ESTABLISHMENT AND MAINTENANCE OF HYBRID BLUEGRASS IN THE TRANSITION ZONE

This chapter will be submitted for publication in the journal HortScience. My primary contributions to this paper include selection of the topic, most of the maintenance, most of the data collection, most of the literature search, and most of the writing.

ABSTRACT

The transition zone is one of the hardest places to maintain high quality turfgrasses. However, hybrid bluegrass (*P. arachnifera* Torr. x *P. pratensis* L.) has been selected for heat and drought tolerance and may offer a new alternative to other turfgrasses. Experiments were conducted in two locations during 2003 and 2004 in Knoxville, TN, USA. Thermal Blue™ was seeded at 50, 100, 150, 200, and 250 kg/ha of seed. Ideal seeding rates for Thermal Blue were between 100 and 150 kg/ha of seed in 2003 and 50 kg in 2004 which produced good quality and cover. Thermal Blue was also seeded in January, April, July, and September of each year with 100 kg/ha of seed. The best time of year to seed Thermal Blue for the fastest turf coverage and highest quality is September, followed by April and January. July seeding should be avoided due to time to reach complete turf coverage and poor turf quality (< 6). Thermal Blue and Dura Blue™ were fertilized with ammonium nitrate at 100, 200, and 300 kg N/ha/yr and urea formaldehyde at 200 and 300 kg N/ha/yr starting in March of each year. These treatments were maintained at 20, 35, and 50 mm mowing heights. Thermal Blue had slightly higher quality evaluations and produced more biomass than Dura Blue throughout the year. Higher fertility regimes increased quality evaluations in April but

decreased quality evaluations in October. Increasing mowing heights increased quality and decreased biomass production for both grasses. Thermal Blue and Dura Blue are adapted for the transition zone, however later summer heat stress may cause decreased turf quality in the fall.

Nomenclature: ammonium nitrate; urea formaldehyde; hybrid bluegrass (*P. arachnifera* Torr. x *P. pratensis* L.) 'Thermal Blue' and 'Dura Blue'.

Additional Index Words: seed, fertility, mowing heights.

Abbreviations: MAS, months after seeding

INTRODUCTION

Kentucky bluegrass has been adapted to most of the transition zone. However, growing and maintaining this species throughout the year in the transition zone can be difficult. High humidity and high temperatures associated with summer and droughty soil conditions are often too stressful for Kentucky bluegrass to thrive under these conditions. Diseases such as rust (*Puccinia graminis* Persoon subsp. *graminicola* Urban) and dollar spot (*Sclerotinia homoeocarpa* Bennett) can cause injury and reduced stand density in Kentucky bluegrass (Wang and Huang 2004, Landshchoot and Park 1997).

Selective breeding has improved many turfgrass species (Shearman, 1999). Recently, The Scotts Company[4] released 'Thermal Blue' and 'Dura Blue' hybrid bluegrass. Thermal Blue and Dura Blue hybrid bluegrass (*P. arachnifera* Torr. x *P.*

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[4]The Scotts Company, 14111 Scottslawn Rd., Maryville, OH 43041

pratensis L.) are inter-specific hybrids of Texas bluegrass (*P. arachnifera* Torr.) and traditional Kentucky bluegrass (*P. pratensis* L.). Hybrid bluegrass was bred for increased heat and drought tolerance of Texas bluegrass and the desirable turfgrass quality of Kentucky bluegrass (Abraham et al. 2004).

Kentucky bluegrass is widely utilized in the transition zone and in the colder northern climates where previous research has established seeding rates, nitrogen fertility, and mowing heights are used (Beard 1973, Bredakis 1959, Jagschitz and Skogley 1965, Juska et al. 1955, Juska and Hanson 1961, Kuhn and Kemp 1939, Skogley and Ledeborer 1968). In general, Kentucky bluegrass should be seeded between 50 to 75 kg/ha which produces 2 to 4 seed per cm^2 (Beard 1973). However, many of the turfgrass breeders and developers have had problems with low seed yield, low germination rates, and poor seedling vigor in many of the new hybrid varieties (Jim Frelich, personal communication). A literature search revealed no published information regarding seed establishment and maintenance of the hybrid bluegrass. The objectives of these experiments were to 1) determine optimal seeding rates, 2) establish the correct seed timing, and 3) investigate the interaction of mowing height and fertility requirements for these turfgrasses in the transition zone.

MATERIALS AND METHODS

General Procedures. Two separate field experiments were conducted from 2003 to 2005 at the Plant Science Farm near Knoxville, TN. The soil type was a Sequatchie loam (fine-loamy, siliceous, thermic Humic Hapudult), which was 39% sand, 46% silt, 15% clay with 1.0% organic matter and a pH of 6.5. Study areas were treated with the soil fumigant dazomet at 390 kg ai/ha on 23 August 2003 and 27 August 2004 to reduce weed and disease pressure. Dazomet was tilled into the soil immediately after application and the area was irrigated at 1 to 1.5 cm of water several times per day for seven days. Study areas were tilled 14 d following dazomet application to insure complete release of phytotoxic gasses before seeding grasses.

Thermal Blue and Dura Blue were evenly seeded at 100 kg/ha (2 seed/cm^2), unless otherwise stated, and incorporated into the soil using a spring tooth rake. Seeding occurred on 29 September 2003 and 25 September 2004, unless otherwise stated. Irrigation was applied on an as needed basis to establish and maintain a high quality turfgrass. Nitrogen fertilization was applied at 25 kg N/ha/mo on newly seeded areas from September to December. Also, supplemental fertilization with 50 kg/ha of P and K using triple super phosphate and potassium chloride were applied at seeding. Spring fertilization included 49 kg N/ha on 1 March with 25 kg N/ha applied every six wk thereafter until the termination of the study, unless otherwise noted. Fertilization was with a 29N-1.3P-3.3K analysis commercial fertilizer, unless otherwise stated. All studies were mowed twice per week from 15 October to 01 January and again from 15 March to the termination of each study. Times of seeding and seeding rate studies were mowed at a 50 mm height, and were only conducted with Thermal Blue due to limited seed availability of Dura Blue. Oxadiazon was applied at 2 kg ai/ha on the first wk of April each year for preemergence crabgrass and goosegrass control on all studies except the seed timing study where plots were hand weeded. All plots were 1.5 by 3 m and all studies were arranged in a randomized complete block design with four replications.

Seeding Rate. Thermal blue was seeded at 50, 100, 150, 200, and 250 kg seed/ha (1to 4 seed/cm^2). Visual observations for quality and cover and were recorded monthly for 11 months after seeding (MAS). Quality was based on color, density, uniformity, texture, and disease incidence or environmental stress effect. Quality was visually evaluated on a scale of 1 to 9, with 1 being brown or dead turfgrass and 9 being ideal turfgrass (Skogley and Sawyer 1992). A quality standard of 6.5 was the minimum acceptable turfgrass quality evaluation. Percent cover was visually evaluated on a scale of 0 to 100, with 0 being no turfgrass and 100 being dense turfgrass.

Time of Seeding. Thermal Blue was planted in September, January, April, and July of each year to establish the best time of year for planting. Glyphosate was applied as a 2% solution two wk before seeding for weed control. All plots were lightly tilled the day of planting and seeds were evenly broadcast and incorporated with a spring tooth rake. Plots were fertilized at planting as previously described. Plots were monitored monthly for quality and percent cover for 11 to 12 MAS.

Fertility and Mowing Heights. Varieties and fertility regimes were arranged in a factorial treatment design. Thermal Blue and Dura Blue were fertilized with ammonium nitrate at 100, 200, and 300 kg N/ha/yr and were applied at 8, 16, and 24 kg N/ha/month and urea formaldehyde at applied at 200 and 300 kg N/ha/yr and were applied at 66 and 100 kg N/ha in March, June, and September. Also, 50 kg/ha of P and K were applied as triple super phosphate and potassium chloride in March of each year. All fertilizer treatments were applied on approximately the 15th of each month. Mowing heights of 20, 35, and 50 mm that were 1 m wide were randomly superimposed as strip plots across each replication. Plots were mowed twice per week. Plots were visually evaluated for quality as previously described. From March to December, turfgrass clippings were collected monthly approximately 15 d following fertilizer applications. Dry weights of clipping samples were recorded following 4 d of forced air drying at 65 C.

SAS (1999) Proc Mixed was utilized to perform analysis of variance for turfgrass cover, quality, and clipping yield. All data were checked for equal variance and arcsine square root transformation were performed when necessary as determined by the Shapiro-Wilk statistic; however untransformed means are presented for clarity. Main effects and all possible interactions were tested using appropriate expected mean square values as recommended by McIntosh (1983). Data were pooled across studies where possible. Means were separated using Fisher's Protected LSD at the 5% significance level or regressed using nonlinear regression models in Sigma Plot[5]. Single degree of freedom contrasts were used to determine differences in seeding rates.

RESULTS AND DISCUSSION

Seeding Rate. There were no differences in Thermal Blue percent cover among years however; seeding rates, MAS, and there interactions (test for repeated measures) were significant. Therefore data were separated accordingly and regressed. Seeding rates for Thermal Blue fit (r^2=0.99) an exponential rise to the max equation (Figure 4). Regression analysis indicated that Thermal Blue seeded in September provided complete ground

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[5] Systat Software, Point Richmond, CA 94804-2028

cover by February (5 MAS). Contrast showed that 150 kg/ha of seed provided more complete cover than 100 kg/ha of seed at 2 MAS (Table 2). Contrasts also showed 150, 200, and 250 kg/ha of seed provided more complete cover than 50 and 100 kg/ha of seed; however these differences were only at 2 and 3 MAS. Also, there were no differences in seeding rates ≥ 150 kg/ha. By 5 MAS, there were no differences in cover based on the amount of seed applied. This indicates that sod producers seeding at lower rates can expect good cover by 5 MAS. Homeowners and turf professionals who want more rapid cover should use higher seeding rates.

There were significant differences in Thermal Blue quality among years, seeding rates, MAS, and there interactions. Data were separated by year and reanalyzed. In 2003 Thermal Blue quality among seeding rates and MAS were significant however, in 2004 only MAS were significant. Therefore, seeding rate quality were separated in 2003 and pooled in 2004 and regressed. Quality of seeding rates fit ($r^2 \geq 0.95$) an exponential rise to the max equation for both years (Figure 5). By 2 MAS only seeding rates above 150 kg/ha were above the minimum level of 6.5. However, Thermal Blue quality continued to improve and by February (5 MAS) all seeding rates were ≥ 6.5. By, July (10 MAS) no difference could be ascertained from any of the seeding rates. Contrast analysis showed no differences in Thermal Blue quality when seeded at 50 and 100 kg/ha of seed regardless of MAS (Table 2). Contrasts also showed that turf quality when seeded at 100 and 150 kg/ha were different only at the 2 and 7 MAS evaluation. However, 50 and 100 kg/ha were significantly lower than 150, 200, and 250 kg/ha at 2 to 9 MAS indicating better quality from the higher seeding rates. There were no differences in 150 vs. 200 and 250 kg/ha at any timing. In 2004, there were no significant differences among any of the treatments and quality evaluations of 7.5 could be observed by 2 MAS. Differences in years may be due to differing seed lots, in which seed weights play a large role in seedling germination and vigor (Larsen and Andreasen 2004).

Time of Seeding. There were no differences in percent cover for Thermal Blue among years for the time of seeding. However, the time of seeding, MAS, and there interaction was significant, therefore time of timings were pooled over years and regressed over time. Seed timing for Thermal Blue fit ($r^2 \geq 0.90$) an exponential rise to the max equation (Figure 6). Thermal Blue cover was fastest at the September seeding date and complete cover could be expected by 5 MAS. April and January were slower and took from 7 MAS to achieve complete cover. July seeding would not be recommended in the transition zone due to the time required to achieve complete cover (80% at 11 MAS).

There were no differences in Thermal Blue turf quality among years for the seed timing. However MAS, seed timing, and their interaction were significant, therefore seed timings were separated and regressed over time. Seed timing for Thermal Blue fit a sigmoidal shaped curve ($r^2 \geq 0.86$). The differences in regression equations were due to the January data, where the seed lay dormant until the end of February before germination. This delay resulted in lower quality ratings up to 5 MAS (Figure 7). However, January seeding had the highest quality evaluations from 11 MAS. July seeding performed the worst, with quality scores that remained below the minimum 6.5 for the duration of the studies. This may have been due to seedling mortality in August and subsequent slow recovery.

Fertility and Mowing Heights. Cultivar, months, months by cultivar, months by height, and year by month by cultivar by fertility by mowing height were all significant for turf quality (Table 3). Therefore quality data were separated by month and reanalyzed. There were significant differences in quality evaluations for cultivars, treatment, and mowing heights in April, mowing heights in July, and treatment and mowing heights in October (Table 3). However, no interactions occurred between cultivar, treatments, or mowing heights at any of the dates and therefore only the main effects of quality will be discussed.

Thermal Blue had higher quality evaluations than did Dura Blue in April (Table 4). This was due to the finer texture of Thermal Blue however, both Dura Blue and Thermal Blue exhibited excellent turf quality. In July, there were no differences in turf quality among the two varieties. The slight decrease in quality of Thermal Blue was due to a slightly lighter green color during the summer. By October of each year, both varieties had fallen below the minimum 6.5 quality evaluation. This was mostly due to the increased heat stress from the rest of July and August. However, both varieties were starting to recover by October.

Cultivars, month by cultivar, month by height were all significant for biomass. Therefore biomass data were separated by month and reanalyzed (Table 5). There were significant differences in turf clipping dry weights for cultivars, treatment, and mowing heights in April, mowing heights in July, and treatment and mowing heights in October However, no interactions occurred between cultivar, treatments, or mowing heights at any of the dates and therefore only the main effects of biomass will be discussed.

Thermal Blue produced 39 kg/ha more clipping dry weight/ha than did Dura Blue in April (Table 4).

Thermal Blue and Dura Blue responded similarly for all of the fertilizer regimes and turf quality differences could only be seen in April and October (Table 6). In April, ammonium nitrate at 300 kg N/ha produced the highest turf quality and urea formaldehyde at 200 kg N/ha produced the lowest quality. Although these evaluations were statistically different, the actual differences were small and evaluations were indicative of acceptable turf quality. By October turf quality had completely reversed. Urea formaldehyde at 200 kg N/ha had the highest quality score and ammonium nitrate at 300 kg N/ha had the lowest quality score. Also, only urea formaldehyde and ammonium nitrate at 200 and 100 kg N/ha were acceptable and above the minimum quality rating of 6.5. In previous research, decreased rooting has been observed from high N applications (Badra et al. 2005, Bilgili and Acikgoz 2005). The reversal of turfgrass quality from spring to fall is presumably due to increased summer heat stress and decreased rooting by the higher N treatments. There were also no quality advantages in using slow-release (urea formaldehyde) over fast-release (ammonium nitrate) nitrogen fertilizers. However, many turf professionals may chose to use slower release fertilizers due to there ease of application, reduced turfgrass injury potential, and longevity. Also, the factorial treatment arrangement with strip plots as sub plots probably resulted in decreased statistical power and may have masked differences in turf quality.

Thermal Blue and Dura Blue produced about the same amount of clippings at all dates regardless of fertilizers used (Table 6). This indicates that lower fertility rates using either fast or slow release fertilizers is acceptable and clipping yield is relatively the same. In previous research, Kentucky bluegrass was shown to have better turf quality and decreased weed pressure when clippings were returned to the turfgrass canopy (Heckman et al. 2000, Kopp and Guillard 2002).

Thermal Blue and Dura Blue responded the same for all mowing heights and increased mowing heights improved turf quality (Table 7). In April and July, there was no difference in quality with 35 or 50 mm mowing heights and the 20 mm mowing height had the lowest turf quality. However, there was little difference in these quality evaluations and all were acceptable. By October, the 35 and the 50 mm mowing heights were different but both were acceptable. However, the 20 mm mowing height had dropped below the 6.5 minimum quality score. This research indicates that Thermal Blue and Dura Blue should be maintained at higher mowing heights to avoid decreased quality.

Thermal Blue and Dura Blue responded the same for all mowing heights and increased mowing heights decreased their clipping yield (Table 7). April was the only evaluation date that there were any statistical differences. Both grasses produced the most clippings at the lower heights of cut. This was probably due to decreased efficiency of the reel mower use to collect clipping at the higher mowing height and not the growth habit of the grass.

Thermal Blue should be seeded anytime from September to April, which gives adequate time for seed germination and growth before the hot summer months. July seeding in the transition zone is not recommended. Thermal blue performed well in seeding trials, however the addition of a small percentage of perennial ryegrass, tall fescue, and/or red fescue may decrease the time to reach the desired cover and quality and decrease the chance of erosion (Beard 1973, Funk and Engel 951).

Overall, seeding Thermal Blue at 100 to 150 kg/ha would be ideal for most homeowners or turf professionals. This is slightly higher than traditional Kentucky bluegrass seeding rates (Beard 1973). Sod producers may consider using 50 kg/ha of seed to lower the seed cost since there was little difference in the amount of cover by 10 MAS and rapid turf growth soon after seeding is not as important as with homeowners, golf course superintendents, or sports field managers.

These studies indicate that Dura Blue and Thermal Blue are very comparable in quality and clipping production. Also, increased mowing heights increased the quality scores and decreases the biomass produced for both grasses at the end of the year. Higher fertility regimes in the spring will increase the quality scores in the spring; however, this may cause plants to become more succulent during the summer and increase disease occurrence. Thermal Blue and Dura Blue can be used in the transition zone and can be maintained under many fertilizer and mowing height regimes.

Both Thermal Blue and Dura Blue are high maintenance turfgrasses and are not well suited for low maintenance turf situations. They are slower to form a dense, lush turf than tall fescue which is more common in the transition zone. Thermal Blue will require frequent mowing due to its aggressive growth habits and dethatching will be required annually when using either grasses. Irrigation will also be required in the transition zone especially during summer heat stress. Both grasses are susceptible to the disease dollar spot and fungicide applications will be necessary to maintain a high quality turf during late summer and fall.

ACKNOWLEDGEMENTS

The authors thank the Tennessee Agricultural Experiment Station for support of our research. Mention of products or trade names do not constitute endorsement by the University of Tennessee and are included as reference only. These products should be used in accordance with the manufacturer instructions.

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PART IV

HYBRID BLUEGRASS RESPONSE TO THREE PLANT GROWTH REGULATORS IN THE TRANSITION ZONE.

This chapter will be submitted for publication in the Journal of Applied Turf. My primary contributions to this paper include selection of the topic, most of the maintenance, most of the data collection, most of the literature search, and most of the writing.

ABSTRACT

Plant growth regulators are known to have differential effects on grass cultivars. The objective of this research was to determine tolerance to commonly used plant growth regulators on 'Thermal Blue™', a new hybrid bluegrass. In the tolerance study during 2004 and 2005, paclobutrazol at 1100 g ai/ha caused significant injury (>15%). In both years, color and quality improvements were sporadic for all plant growth regulators and no trends were observed. Only paclobutrazol at both application rates decreased turfgrass clippings consistently compared to the untreated plots. In the mowing height by plant growth regulator trial, paclobutrazol and trinexapac-ethyl color and quality evaluations were no different than the untreated turf. Ethephon was the only plant growth regulator to provide decreased clipping dry weights consistently for all mowing heights. However ethephon caused unacceptable visual color and quality. Increasing mowing heights was more important in maintaining a healthy turf than any other factor. There were no advantages in treating Thermal Blue with ethephon, paclobutrazol, or trinexapac-ethyl.

Nomenclature: ammonium nitrate; urea formaldehyde; hybrid bluegrass (*P. arachnifera* Torr. x *P. pratensis* L.) 'Thermal Blue'.

Additional Index Words: seed, fertility.

Abbreviations: PGR, plant growth regulator; WAIT, weeks after initial treatment

INTRODUCTION

The transition zone in one of the hardest places to grow and maintain healthy turfgrass stands (Beard 1973). Turfgrass breeders have made efforts to produce Kentucky bluegrass varieties that are more heat tolerant and adapted to the temperature extremes of the transition zone. The Scotts Company[6] released a new inter-specific hybrid bluegrass (*P. arachnifera* Torr. x *P. pratensis* L.), denoted as 'Thermal Blue™'. Hybrid bluegrass was bred for increased heat and drought tolerance of Texas bluegrass and the desirable turfgrass quality and color of Kentucky bluegrass (Abraham et al. 2004).

Plant growth regulators (PGR) are frequently used in turf to decrease clipping yield, improve turf quality, and inhibit seedhead production (Watcshke et al. 1992). Trinexapac-ethyl and paclobutrazol inhibit gibberellic acid (GA) synthesis within the plant and are used to enhance turfgrass color, quality, and decreased clipping yields (Ervin and Koski 2001, Lickfeldt et al 2001, Rademacher 2000, Steinke and Stier 2003). Trinexapac-ethyl has also been shown to decrease the incidence of the foliar disease dollar spot (*Sclerotinia homoeocarpa*) (Lickfelt et al. 2001). However, trinexapac-ethyl decreases heat tolerance of turf by reducing cell membrane stability in Kentucky bluegrass during heat stress (Heckman et al. 2002). Also, trinexapac-ethyl does not inhibit seed-head production like a GA inhibitor such as paclobutrazol due to a different

[6]The Scotts Company, 14111 Scottslawn Rd., Maryville, OH 43041

site of action during GA synthesis (McCullough 2005). Paclobutrazol inhibits GA early during synthesis whereas trinexapac-ethyl inhibits GA during late synthesis (Rademacher 2000). This is due to differing sites of action during GA synthesis (Rademacher 2000). Paclobutrazol is commonly used for annual bluegrass (*Poa annua* L.) suppression in creeping bentgrass (*Agrostis stolonifera* L.) greens (Woosley et al. 2003). Paclobutrazol also decreases the incidence of the foliar disease dollar spot (Burpee et al. 1996). Paclobutrazol can reduce turfgrass color and quality during summer heat stress (Symington et al. 1986).

Ethephon is a common plant growth regulator used in turf. Ethephon decomposes to produce the plant hormone ethylene. Plants naturally release ethylene when they are injured or during times of stress which inhibits growth (Taiz and Zeiger 2002). Turf discoloration from exogenous applications of ethylene is common in both warm- and cool-season grasses. Ethephon has been shown to cause injury in warm-season grasses (Shatters 1998). However, no long-term adverse effects have been shown from ethephon applications to Kentucky bluegrass (Christians 1985, Christians and Nau 1984, Diesburg and Christians 1989).

A literature search revealed no information on hybrid bluegrass, including Thermal Blue, and there sensitivity to plant growth regulators. The objectives of this research were to 1) determine the effects of trinexapac-ethyl, paclobutrazol, and ethephon applied at 1 and 2 times the normal use rate for traditional Kentucky bluegrass, and 2) determine the effects of mowing height and trinexapac-ethyl, paclobutrazol, and ethephon applications on hybrid bluegrass.

MATERIALS AND METHODS

Two separate field experiments were conducted from 2003 to 2005 near Knoxville, TN. The soil type was a Sequatchie loam (fine-loamy, siliceous, thermic Humic Hapudult), which was 39% sand, 46% silt, 15% clay with 1.0% organic matter and a pH of 6.5. Study areas were treated with the soil fumigant dazomet at 390 kg ai/ha on 23 August 2003 and 27 August 2004 to reduce weed and disease pressure. Dazomet was tilled into the soil immediately after application and the area was irrigated at 1 to 1.50 mm of water several times per day for seven days. Study areas were tilled 14 d following dazomet application to insure complete release of dazomet gasses before seeding. Thermal Blue hybrid bluegrass was broadcast seeded at 100 kg/ha and incorporated into the soil using a drag mat. Seeding occurred on 29 September 2003 and 25 September 2004. Irrigation was applied on an as needed basis to establish and maintain a high quality turf. Fertilization was applied at 25 kg N/ha/mo on newly seeded areas from September to December. Spring fertilization included 49 kg N/ha on 1 March with 25 kg N/ha applied every six wk thereafter until the termination of the study. A granular application of oxadiazon was applied at 2 kg ai/ha during the first wk of April each year for preemergence crabgrass and goosegrass control.

In a PGR tolerance study ethephon was applied at 3800 and 7600 g ai/ha, paclobutrazol at 570 and 1100 g ai/ha, and trinexapac-ethyl at 230 and 460 g ai/ha at monthly intervals for 3 months starting on 2 June 2004 and 15 May 2005. These application rates correspond to 1 and 2 times the highest normal single application rates for Kentucky bluegrass as recommended by there manufacturer. However, application timings were more frequent than the manufacturer recommendations for ethephon and paclobutrazol. PGR application rates and timings were used to determine a margin of safety for PGR applications to Thermal Blue. Treatments were arranged in as a randomized complete block design and were mowed with a rotary mower at 50 mm once per week.

In a separate study, plant growth regulators were applied as main effects. Ethephon, paclobutrazol, and trinexapac-ethyl were applied at 3800, 280, and 230 g ai/ha, respectively. Mowing heights of 20, 35, and 50 mm were applied as strip plots across the main effects. Plant growth regulators were applied at monthly intervals for 6 months starting on 2 June 2004 and 15 May 2005. Strips were mowed twice per week with a reel mower throughout the study. Application rates of plant growth regulators were based on previous experience with these plant growth regulators at these mowing heights and correspond to the highest normal use rates for ethephon and trinexapac-ethyl and the lowest normal use rate for paclobutrazol on Kentucky bluegrass. However, application timings were more frequent for ethephon and paclobutrazol than recommended. Rates and timings were chosen to establish a margin of safety, in most cases, and are higher than would be recommended for use. In both studies, paclobutrazol treatments were applied and watered in with 1 cm of water supplied as overhead irrigation. Ethephon and trinexapac-ethyl treatments were applied 30 to 45 min later after foliage had dried. An untreated check was included for comparisons in both experiments.

Plant growth regulators were applied to 1.5 by 3 m plots using a CO_2-pressurized backpack sprayer calibrated to deliver 215 L/ha. Visual color, visual quality, and clipping dry weights were taken 15 d after each plant growth regulator application. Visual estimations of Thermal Blue injury were also recorded for the plant growth regulator tolerance study. Thermal Blue injury evaluations were recorded on a scale of 0 to 100% with 0 being no injury, 100 being turf death, and 15% being maximum acceptable injury. Visual color was based on a 1 to 9 scale, with 1 being brown turf and 9 being ideal green turf. Visual quality was based on turf color, density, uniformity, texture, and disease incidence or environmental stress effect, and was evaluated on a scale of 1 to 9, with 1 being dead turf, and 9 being ideal turfgrass (Skogley and Sawyer 1992). A turf quality standard of was 6.5 set as the minimum acceptable quality. Turfgrass clippings were collected and dry weights were recorded following 4 d of forced air drying at 65 C.

Analysis of variance was conducted using SAS (1999) Proc Mixed. Data were normally distributed with equal variance and arcsine square root transformations of crop injury, cover, quality, and clipping dry weight evaluations did not affect conclusions. Main effects and all possible interactions were tested using appropriate expected mean square values as recommended by McIntosh (1983). Means were separated using Fisher's Protected LSD at the 5% level of probability. In the plant growth regulator tolerance study treatments, months, years, and/or there interactions for injury, color, quality, and dry weights were all significant (Table 8). Therefore data were separated by years and treatment means were displayed for each month. In the plant growth regulator by mowing height study treatment, mowing heights, months, and there interactions for color, quality, and dry weight were all significant (Table 9). However, years were not significant, therefore data pooled over years and means for the interaction of plant growth regulators and mowing heights are displayed for each month.

RESULTS AND DICSUSSION

Plant Growth Regulator Tolerance. Thermal Blue did not display any visual injury in June of either year (Table 10). Paclobutrazol at 1100 g ai/ha displayed 30% injury levels in July and Aug of 2004, respectively. In July 2005, injury from paclobutrazol at 570 and 1100 g ai/ha was > 19% and by August 2005 only paclobutrazol at 1100 g ai/ha was 15%. Slight injury (3 to 8%) from both trinexapac-ethyl rates were observed in both years, however this injury appeared to be transient and was no longer visible in August.

Ethephon at 3800 and 7600 g ai/ha and trinexapac-ethyl at 460 g ai/ha showed decreases in Thermal Blue color scores compared to the untreated plots in June 2004 (Table 11). However, no differences were observed in June 2005. Ethephon treatments had recovered and paclobutrazol at 570 and 1100 g ai/ha and trinexapac-ethyl at 460 g ai/ha had low turf color scores compared to the untreated treatments in July 2004. In August 2004 there were no differences in the color of Thermal Blue except paclobutrazol at 1100 g ai/ha, which had declined even further. Ethephon at both rates had increased color scores compared to the untreated plots in July 2005. Differences with ethephon treatments were no longer apparent in August. Paclobutrazol and trinexapac-ethyl at 570 and 230 g ai/ha had decreased turf color compared to the untreated areas in July 2005. However, paclobutrazol at 570 g ai/ha and trinexapac-ethyl 230 and 460 g ai/ha both displayed increased color compared to the untreated control in August 2005. The decreased color of paclobutrazol and trinexapac-ethyl treated plots in July and increased color in August is unexplained. However in previous research both paclobutrazol and trinexapac-ethyl were shown to temporarily reduce visual quality (Calhoun and Baird 1998).

No differences in Thermal Blue quality were observed in June 2004 (Table 12). Furthermore, in July and August paclobutrazol at 1100 g ai/ha was the only treatment that had unacceptable turf quality (≤ 6.5). Paclobutrazol at 570 and 1100 g ai/ha in June and paclobutrazol at 1100 g ai/ha in July had unacceptable turf quality in 2005. Also, Thermal blue quality decreased with ethephon at both rates in August 2005, however only the 7600 g ai/ha rate was ≤ 6.5. The decrease in quality with ethephon was mainly due to a change in overall turfgrass texture and not due to turf injury. Both rates of trinexapac-ethyl showed increased turf quality compared to the untreated treatments in July 2005.

Paclobutrazol caused the most Thermal Blue injury and reduced turf color and turf quality compared to the other plant growth regulator treatments (Table 10, 11, 12). Similar reductions in color and quality were reported when 'Merion' Kentucky bluegrass was treated with paclobutrazol during heat stress (Symington et al. 1986). The reduction in color may be due to reduced photosynthate partitioning to the roots (Hanson and Branham 1987).

No dry weight clipping data were taken in June 2004. There were no differences in Thermal Blue clipping dry weights in June 2005 (Table 13). However, in July and August in both years paclobutrazol at both rates reduced clippings compared to the untreated control. Trinexapac-ethyl at 230 g ai/ha July 2004 was the only other treatment to reduce clippings compared to the untreated treatments.

Ethephon and trinexapac-ethyl did not consistently reduce clippings, although there were no deleterious effects following the use of these products in this study. In previous research, Lickfeldt et al. (2001) showed reduced clippings with trinexapac-ethyl at 290 g ai/ha at 4 and 6 wk reapplication intervals compared to the untreated plots.   Difference in clippings produced is probably a varietal response and further studies are needed to further refine the effective dosage of trinexapac-ethyl on Thermal Blue.

Plant Growth Regulators by Mowing Heights. There was little difference in Thermal Blue color in June for each mowing height (Table 14). However, Thermal Blue treated with ethephon and paclobutrazol were darker green than the untreated control. In July and August ethephon treatments mowed at 20 mm, and in September to November with ethephon at all mowing heights, had reduced turf quality compared to the untreated treatments. This was probably due to the frequent PGR application timings. Paclobutrazol increased turf color compared to the untreated turf for most months and provided the darkest Thermal Blue color scores. Trinexapac-ethyl was not significantly different from the untreated turf at any month. Increasing mowing height increased overall turf color especially during the end of summer (September) when heat stress decreased over all color of all untreated plots, regardless of PGR or mowing height, to unacceptable levels.

Thermal Blue quality was not affected by plant growth regulator application or mowing heights in June (Table 15). In July ethephon treatments mowed at 20 mm was unacceptable (< 6.5), in August turf treated with ethephon and mowed at 20 and 35 mm was unacceptable and by September all ethephon treatments were unacceptable. Decreased turf quality when treated with ethephon was probably due to aforementioned application timings. Paclobutrazol and trinexapac-ethyl application resulted in little statistical advantage.

Overall, clipping dry weights decreased with increased mowing heights (Table 16). Clippings were also much lower in the fall than in the early summer for all treatments. Ethephon decreased the August clipping dry weights at 20 mm and in September at all mowing heights to the comparable mowing height of the untreated plots. Paclobutrazol and trinexapac-ethyl were not different from the untreated turf plots, except in September, where both paclobutrazol and trinexapac-ethyl decreased dry weights when compared to similar mowing heights in the untreated treatments.

Thermal Blue exhibited good tolerance to trinexapac-ethyl. However, ethephon and paclobutrazol applications resulted in slightly lower quality and color ratings in some cases. Lower application rates of ethephon and/or increased time between sequential treatments probably would result in decreased injury, increased color, and increased quality, however this is speculative. Previous research showed tank-mixing ethephon and trinexapac-ethyl reduces the chance of discoloration from ethephon in creeping bentgrass (Kane and Miller 2003).

Increasing mowing height seemed to decrease clipping dry weights more consistently than any other factor. Thermal Blue grew faster at the 20 mm mowing height, indicating that the 50 mm mowing height would reduce the maintenance for turf practitioners. Increased mowing heights also increased Thermal Blue quality and color more than plant growth regulators. This was especially apparent in September when color and quality scores decreased due to heat stress and the 20 mm mowing heights were the most affected. Mowing at the proper height has long been known to produce healthier, denser, turfgrass stands (Beard 1973, Juska et al 1955). Also, increasing mowing height during times of stress decreases the likelihood of other biotic stresses such as disease (Beard 1973).

Previous research showed no long term adverse effects from turf treated with ethephon, although multiple applications were not investigated (Christians 1985, Christians and Nau 1984, Diesburg and Christians 1989). Lickfeldt et al. 2001 also showed consistent reduction of clippings and increased color and density from five trinexapac-ethyl applications at 170 to 290 g ai/ha on Kentucky bluegrass. In these studies there were no advantages in using ethephon, paclobutrazol, or trinexapac-ethyl on Thermal Blue.

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The authors thank the Tennessee Agricultural Experiment Station for support of our research. Mention of products or trade names do not constitute endorsement by the University of Tennessee and are included as reference only. These products should be used in accordance with the manufacturer instructions.

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PART V

HYBRID BLUEGRASS TOLERANCE TO PREEMERGENCE AND POSTEMERGENCE HERBICIDES

This chapter will be submitted for publication in the journal Weed Technology. My primary contributions to this paper include selection of the topic, most of the maintenance, most of the data collection, most of the literature search, and most of the writing.

ABSTRACT

Field studies were conducted near Knoxville, TN in 2003-2005 to evaluate the response of ‘Thermal Blue', a new inter-specific hybrid bluegrass (*Poa pratensis* L. x *P. arachnifera* Torr.) to commonly applied preemergence (PRE) and postemergence (POST) herbicides for weed management. Thermal Blue exhibited significant injury (>81%) and cover reduction (>57%) to dithiopyr, oryzalin, oxadiazon, pendimethalin, prodiamine, quinclorac, and trifluralin when applied at seeding. In a second study, established Thermal Blue was treated POST with acetolactate synthase (ALS) inhibiting herbicides including bispyribac-sodium, chlorosulfuron, foramsulfuron, halosulfuron, imazapic, imazaquin, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron applied at 1 and 2X the suggested use rates in other grass species. By 5 WAT Thermal Blue treated with foramsulfuron (88 g ai/ha) and trifloxysulfuron (35 g ai/ha) displayed > 26% injury, overall quality ratings of < 5.3, and chlorophyll meter indices were reduced > 21%. However, by 10 WAT trifloxysulfuron at 35 g ai/ha caused the most visual injury (7%) and reduced turf quality (6.9). In a third study, established Thermal Blue displayed some tolerance to clethodim, diclofop-methyl, fluazifop-p-butyl, and sethoxydim applied at 0.5, 1, and 2X registered turfgrass use rates. Unacceptable injury (>15%) was observed with clethodim at 280 and 560 g ai/ha, fluazifop at 420 g ai/ha and sethoxydim at 630 g ai/ha 5

WAT. These treatments also reduced quality (< 5) and chlorophyll content (25-37%) when compared to the untreated control. By 10 WAT only clethodim at 560 g ai/ha displayed injury (14%) and reduced chlorophyll index (11%). However, no differences in quality were observed at 10 WAT for any POST graminicides.

Nomenclature: bispyribac-sodium; chlorosulfuron; clethodim; diclofop-methyl; dithiopyr; fluazifop-p-butyl; foramsulfuron; halosulfuron; imazapic; imazaquin; metsulfuron; oryzalin; oxadiazon; pendimethalin; prodiamine; quinclorac; rimsulfuron; sethoxydim; sulfosulfuron; trifloxysulfuron; trifluralin; Kentucky bluegrass, *Poa pratensis* L. x *P. arachnifera* Torr., 'Thermal Blue'.

Additional index words: Chlorophyll index, chlorophyll meter, injury, quality, tolerance.

Abbreviations: ALS, acetolactate synthase; POST, postemergence; PRE, preemergence; WAT, weeks after treatment.

INTRODUCTION

'Thermal Blue™' is a new inter-specific hybrid bluegrass (*Poa pratensis* L. x *P. arachnifera* Torr.) recently released by The Scotts Company[7]. Traditionally, Kentucky bluegrass is not used in the southern part of the turfgrass transition zone due to a lack of heat, drought, and disease tolerance. The inter-specific hybrid bluegrass varieties have potentially displayed the increased heat and drought tolerance of Texas bluegrass (*P.*

[7] The Scotts Company, 14111 Scottslawn Rd., Maryville, OH 43041.

arachnifera Torr.) and the improved turfgrass quality and color of traditional Kentucky bluegrass (*P. pratensis* L.) (Abraham et al. 2004).

Weed control is essential to maintaining a high quality turfgrass. Busey (2003) reported that increasing nitrogen fertility increases the quality and competitiveness of the turfgrasses which decreases the invasion of crabgrass (*Digitaria spp.*) and dandelion (*Taraxacum officinale* Weber), although herbicides should be used to achieve complete weed control. Dithiopyr has shown excellent crabgrass control and no injury to Kentucky bluegrass when applied at least 3 d after emergence (DAE) of Kentucky bluegrass seedlings (Reicher et al. 2000). Other research has also shown excellent tolerance of mature Kentucky bluegrass to dithiopyr at 400 to 1100 g ai/ha (Bhowmik and O'Toole 1993; Neal 1990; Prostak and Ilnicki 1993). However, other dinitroanaline herbicides such as pendimethalin, prodiamine, and oryzalin have shown potential to reduce Kentucky bluegrass rooting (Prostak and Ilnicki 1993).

Single applications of chlorosulfuron or metsulfuron controlled tall fescue 90% in Kentucky bluegrass stands. However, both resulted in Kentucky bluegrass injury during drought stress the following summer when compared to the untreated control (Dernoeden 1990). Applications of quinclorac injured Kentucky bluegrass when applied at 600 g ai/ha 28 DAE and at 1100 g ai/ha 28, 56, and 84 DAE (Neal 1990). Lycan et al. (2001) reported 76 and 39% reduction in Kentucky bluegrass coverage 30 d after treatment (DAT) when applying quinclorac at 1300 and 600 g ai/ha.

A major problem with the introduction of a new turfgrass cultivar, particularly a hybrid, such as Thermal Blue is determining sensitivity to commonly used herbicides.

The objectives of our research were to: 1) determine the impact of commercially available turfgrass PRE herbicides on the establishment Thermal Blue 2) determine the impact of ALS-inhibiting herbicides on established Thermal Blue, and 3) evaluate Thermal Blue tolerance to POST applications of graminicides.

MATERIALS AND METHODS

Two separate field experiments were conducted from 2003 to 2005 near Knoxville, TN. Soil type was a Sequatchie loam (fine-loamy, siliceous, thermic Humic Hapudult), which was 39% sand, 46% silt, 15% clay with 1.0% organic matter and a pH of 6.5. Study areas were treated with the soil fumigant dazomet at 388 kg ai/ha on 23 August 2003 and 27 August 2004 to reduce weed and disease pressure. Dazomet was tilled into the soil immediately after application and area was irrigated at 1 to 1.5 cm of water several times per day for seven days. Study areas were tilled 14 d following dazomet application to insure complete release of dazomet gasses before seeding. Thermal Blue was broadcast seeded at 97 kg/ha and incorporated into the soil using a drag mat. Seeding occurred on 29 September 2003 and 25 September 2004. Irrigation was applied on an as needed basis to establish and maintain a high quality turfgrass. Fertilization was applied at 25 kg N/ha/mo on newly seeded areas from September to December. Spring fertilization included 49 kg N/ha on 1 March with 25 kg N/ha applied every six wk thereafter until the termination of the study. Thermal Blue was mowed twice per week at 50 mm from 15 October to 01 January and again from 15 March to the termination of each study.

PRE herbicides benefin, dithiopyr, oryzalin, oxadiazon, pendimethalin, prodiamine, quinclorac, and trifluralin were applied the day after seeding in 2003 and 2004. Application rates (g ai/ha) are listed in Table 17 and correspond to the typical, registered use rates for a loam soil. In a separate study, ALS-inhibiting investigated POST included; bispyribac, chlorosulfuron, foramsulfuron, halosulfuron, imazapic, imazaquin, metsulfuron, rimsulfuron, sulfosulfuron, and trifloxysulfuron applied at 1x and 2x the typical, registered use rates (Table 18). ALS-inhibiting herbicides were applied when Thermal Blue achieved 100% cover which occurred on 1 June 2004 and 20 April 2005. Also in a another study, gramicides evaluated POST included clethodim, diclofop, fluazifop, and sethoxydim, were applied on 1 June 2004 and 20 April 2005 at ½ x, 1x, and 2x the typical, registered use rates (Table 19). All POST herbicides were applied with an appropriate surfactant, either nonionic surfactant[8] at 0.25% (v/v) or a crop oil concentrate[9] at 1% (v/v). An untreated check was included for comparisons in all experiments.

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[8] Induce® nonionic low foam wetter/spreader adjuvant contains 90% nonionic surfactant (alkylarylpolyoxyalkane ether and isopropanol), free fatty acids, and 10% water. Manufactured by Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

[9] Agri-Dex® crop oil concentrate nonionic adjuvant contains 99% proprietary blend of heavy paraffinic oil, Polyol fatty acid ester and polyethoxylated derivatives.

Each trial was designed as a randomized complete block with four replications of all treatments. Herbicides were applied to 1.5 by 3 m plots using a CO_2-pressurized backpack sprayer calibrated to deliver 215 L/ha. Visual estimations of Thermal Blue injury were recorded 5 and 25 wk after treatment (WAT) for PRE experiment and at 2, 5, and 10 WAT for POST experiments. Thermal Blue injury evaluations were recorded on a scale of 0 to 100% with 0 = no injury, 100 = crop death, and 15% being maximum acceptable injury. Quality was based on color, density, uniformity, texture, and disease incidence or environmental stress effect and was evaluated on a scale of 1 to 9, 1 being brown or dead turf, 9 being ideal turfgrass, with a quality standard of 6.5 set as the minimum acceptable Thermal Blue quality (Skogley and Sawyer 1992). Turfgrass cover evaluations for PRE study were recorded on a scale of 0 to 100% with 0 = no turfgrass and 100 = turfgrass canopy closure. Hand-held chlorophyll meter indices were recorded on the ALS-inhibiting herbicides and POST graminicide studies using a Spectrum[10] CM-1000 chlorophyll meter. Five random sample chlorophyll indices were recorded per treatment for each replication. The chlorophyll meter was held approximately 1 meter perpendicular to the top of the turfgrass canopy and the angle of incidence to horizontal was approximately 45 degrees from perpendicular. All readings were recorded in full,

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Manufactured by Helena Chemical Company, Suite 500, 6075 Poplar Avenue, Memphis, TN 38137.

[10] Spectrum technologies, Plainfield, IL. 60544.

direct sunlight. CM-1000 chlorophyll meter measures chlorophyll content by analysis of ambient and reflected light at two wavelengths (700 and 840 nm) based on a relative chlorophyll index of 0 to 999, where 0 indicates no chlorophyll present while 999 indicates the maximum measurable chlorophyll content. While the chlorophyll meter gives an objective evaluation of injury, the chlorophyll meter indices were difficult to interpret. Therefore, for ease of interpretation, chlorophyll meter indices were normalized to percentages based on the untreated control. There were no differences in rooting depth, month, or there interaction.

Analysis of variance was conducted using SAS (1999) Proc Mixed. Data were normally distributed with equal variance and arcsine square root transformations of crop injury, cover, quality, and chlorophyll meter index evaluations did not affect conclusions. Main effects and all possible interactions were tested using appropriate expected mean square values as recommended by McIntosh (1983). Means were separated using Fisher's Protected LSD at the 5% level of probability. No year or year by treatment interactions were detected and all data were pooled for analysis.

RESULTS AND DISCUSSION

Thermal Blue Tolerance to PRE Herbicides. All soil applied herbicides evaluated caused unacceptable injury (> 81%) and stand reduction (>57 %) in Thermal Blue 25 WAT (Table 17). Similar results were observed by McElroy et al (2004), where quinclorac at 750 and 1500 g ai/ha applied at seeding injured Thermal Blue 24 and 41% 5 WAT. McElroy et al. (2004) demonstrated excellent Thermal Blue tolerance and excellent crabgrass control with mesotrione at 125 and 250 g ai/ha which may offer an alternative to the herbicides we tested.

Thermal Blue Tolerance to ALS-inhibiting Herbicides. Thermal Blue injury 2 WAT from POST ALS-inhibiting herbicide treatments was < 7% and consisted of slight chlorosis (Table 18). Thermal Blue injury increased to unacceptable levels (36 and 26%) with foramsulfuron at 88 g ai/ha and trifloxysulfuron at 35 g ai/ha, respectively, by 5 WAT. By 10 WAT only trifloxysulfuron applied at 35 g ai/ha was different from the untreated control and exhibited any injury (7%).

Thermal Blue quality when treated with ALS-inhibiting herbicides was acceptable (> 6.5) and ranged from 6.8 to 7.5; however none of the treatments were significantly different 2 WAT (Table 18). By 5 WAT, Thermal Blue quality was unacceptable with foramsulfuron applied at 44 and 88 g ai/ha and trifloxysulfuron at 35 g ai/ha. However, by 10 WAT most of the herbicide injury to Thermal Blue was gone, and only trifloxysulfuron at 35 g ai/ha caused turf quality lower than the untreated control.

Chlorophyll meter indices for Thermal Blue treated with ALS-inhibiting herbicides 2 WAT were reduced when compared to the untreated control (Table 18). Indices were decreased 10 to 18% with bispyribac-sodium at 148 and 296 g ai/ha, foramsulfuron at 44 and 88 g ai/ha, imazapic at 105 and 210 g ai/ha, rimsulfuron at 35 and 70 g ai/ha, sulfosulfuron at 105 g ai/ha, and trifloxysulfuron at 17 and 35 g ai/ha. Injury appeared as slight chlorosis and was difficult to discern with visual evaluations. By 5 WAT, Thermal Blue recovered from injury except for applications of foramsulfuron at 88 g ai/ha and trifloxysulfuron at 35 g ai/ha which were 30 and 21% less than the untreated control. There were no differences in chlorophyll meter indexes by 10 WAT, indicating that Thermal Blue recovered from ALS-inhibiting herbicide injury.

Thermal Blue has good tolerance to single POST applications of most ALS herbicides. However, in previous research, multiple fall applications of chlorosulfuron and metsulfuron caused traditional Kentucky bluegrass injury the following summer (Dernoeden 1990). Multiple applications and timings of all ALS herbicides on Thermal Blue should be investigated further. Chlorosis on 'Baron' Kentucky bluegrass was also observed 4 WAT with sulfosulfuron at 6 to 60 g ai/ha (Lycan and Hart 2004), however no chlorosis was observed in our research with Thermal Blue. Based on our findings, foramsulfuron and trifloxysulfuron may cause unacceptable damage to Thermal Blue.

Thermal Blue Tolerance to Graminicides Applied POST. Thermal Blue injury from POST graminicide herbicide treatments was unacceptable (15 %) for clethodim applied at 560 g ai/ha when evaluated 2 WAT (Table 19). However clethodim, fluazifop-p-butyl, and sethoxydim all displayed moderate injury (8-15%) when compared to untreated Thermal Blue. By 5 WAT, clethodim applied at 560 g ai/ha caused 53% injury. However, 32-44% injury was observed with clethodim, fluazifop, and sethoxydim applied at 280, 420, and 630 g ai/ha, respectively, when evaluated 5 WAT. Injury 5 WAT consisted of chlorosis, necrosis, and stand reduction. By 10 WAT, injury to the aforementioned treatments was reduced to 8-14%. At 10 WAT injury consisted only of stand reduction.   Diclofop-methyl produced no injury to Thermal Blue at any rate or evaluation interval. Diclofop-methyl can be used safely to kill weeds such as goosegrass (*Eleusine indica* L. Gaertn.) when applied at 1100 g ai/ha (Johnson 1996).

Thermal Blue quality was unacceptable (< 6.5) for clethodim applications when evaluated 2 WAT at all herbicide rates. However, all treatments except diclofop-methyl were lower than the untreated control (Table 19). By 5 WAT unacceptable quality was observed with clethodim, fluazifop and sethoxydim applied at 280 and 560, 420, 320 and 630 g ai/ha, respectively. By 10 WAT Thermal Blue treated with all graminicides displayed quality above 6.5 and no treatment differences were detected.

Chlorophyll meter indices 2 WAT with clethodim applied at 140, 280, and 560 g ai/ha, fluazifop-p-butyl applied at 210 and 420 g ai/ha, and sethoxydim applied at 160, 320, and 630 g ai/ha were reduced from 13 to 21% (Table 19). Injury observed was chlorosis and small necrotic lesions on Thermal Blue leaves. By 5 WAT, all chlorophyll indices were lower than those recorded 2 WAT and there was much more variability within treatments. Clethodim applied at 560 g ai/ha was the only treatment that displayed decreased (37%) chlorophyll indices compared to the untreated control.

Thermal Blue was susceptible to the PRE herbicides we applied at seeding and should not be used during establishment. Control of most summer annual weeds can be achieved by fall planting which delays germination and maturation of these weeds. Also, summer annual weeds will die at first frost.

Thermal Blue is tolerant of single applications of ALS herbicides with the exception of foramsulfuron and trifloxysulfuron. This gives several options for control of perennial weeds such as tall fescue, white clover, and nutsedges (*Cyperus* spp.). POST grass control with graminicides should be avoided with the exception of diclofop-methyl, which is only labeled for control of goosegrass. Our results indicate many POST weed management options exist for Thermal Blue turfgrass. Thermal Blue responds to POST herbicides similarly to traditional Kentucky bluegrass varieties and our research indicates that herbicides registered for use in Kentucky bluegrass are safe to use in Thermal Blue turfgrass stands.

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PART VI

CARBOHYDRATE ALLOCATION OF FOUR BLUEGRASS SPECIES UNDER HEAT STRESS.

This chapter will be submitted for publication in the journal Crop Science. My primary contributions to this paper include selection of the topic, most of the maintenance, most of the data collection, most of the literature search, and most of the writing.

ABSTRACT

Hybrid bluegrass (*Poa arachnifera* Torr. x *P. pratensis* L.) is proposed to have increased heat tolerance related to greater nonstructural carbohydrate accumulation and more pronounced rooting. The objectives of our experiments were to: 1) compare carbohydrate accumulation in the leaves, crowns, and roots of ‘Thermal Blue’ hybrid bluegrass, ‘Apollo’ Kentucky bluegrass (*Poa pratensis* L.), ‘Supranova’ supina bluegrass (*Poa supina* Schrad.), and ‘Laser’ rough bluegrass (*Poa trivialis* L.) in April, June, and July and 2) compare the relative biomass production of these grasses. All grasses had linear decreases in total nonstructural carbohydrate (TNC) accumulation in the leaves from April to July. However, there was a linear increase in TNC accumulation in the roots hybrid bluegrass and Kentucky bluegrass from April to July. Rooting depths were the same for all species. There was large variation in shoot dry weights for each month. However, crown area and roots exhibited less fluctuation in dry weights, except ‘Laser’ rough bluegrass, which had a 150% decrease in root dry weights from April to July. These results indicate that hybrid bluegrass and Kentucky bluegrass have more heat tolerance associated with a reallocation of TNC from the leaves in April to the roots in July.

Nomenclature: Hybrid bluegrass, (*Poa arachnifera* Torr. x *P. pratensis* L.) 'Thermal Blue'; Kentucky bluegrass, (*Poa pratensis* L.) 'Apollo'; Rough bluegrass, (*Poa trivialis* L.) 'Laser'; Supina bluegrass, (*Poa supina* Shcrad.) 'Supranova'.

Additional index words: glucose, fructose, sucrose, starch, total nonstructural carbohydrates.

Abbreviations: EU, enzyme units; TNC, total nonstructural carbohydrates.

INTRODUCTION

Cool-season turfgrasses have traditionally been difficult to manage in the transition zone. Optimal air temperatures for shoot growth of cool-season turfgrass is 16-24 C (Beard 1973), however temperatures in the transition zone often approach 30 C or higher during the summer months. Traditionally, tall fescue has been the cool-season turfgrass of choice in the transition zone. Unfortunately, stress associated with the hot, humid summers often decreases tall fescue growth and increases the frequency of disease occurrence. Recent introductions of hybrid bluegrass (*Poa arachnifera* Torr. x *P. pratensis* L.) have displayed the heat and drought tolerance of Texas bluegrass (*P. arachnifera* Torr.) and the desirable turfgrass quality and color of Kentucky bluegrass (*P. pratensis* L) (Abraham et al. 2004). Increased heat tolerance is thought to be due to higher root densities which may allow for more total nonstructural carbohydrate (TNC) storage (Frelich personal communication).

Nonstructural carbohydrates are an important energy reserve used by plants to survive stress conditions (Watschke et al. 1972, 1973; Beard 1973; Howard and

Watschke 1985, 1991; Hull 1992). Several studies in growth chambers have shown that increasing temperatures decrease carbohydrate availability (Al-Khatib and Paulsen 1989; Moffat et al. 1990; Liu and Huang 2000; Xu and Huang 2000a, 2000b; Liu and Huang 2001). Reductions in photosynthetic rate, chlorophyll content, carbohydrate accumulation, and cell membrane stability due to heat stress have been observed in creeping bentgrass, Kentucky bluegrass, and perennial ryegrass (Wehner and Watschke 1984; White et al. 1998; Howard and Watschke 1991; Huang et al. 1998). Roots have been reported to be more sensitive to heat stress than shoots (Xu and Huang 2000 a, 2000b). In creeping bentgrass, decreased carbohydrates are associated with decreased root growth, tiller production, shoot growth and overall plant health (Carrow 1996; Xu and Huang 2000 a, 2000b, 2001; Sweeney et al. 2001).

Turfgrass accumulates TNC as the monosaccharides glucose and fructose, the disaccharide sucrose, and various oligosaccharides, starches, and fructans (Smith 1972). Aldous and Kaufmann (1979) observed root death in Kentucky bluegrass at high temperatures which resulted in decreased in shoot growth. This decline was suggested to be from reductions in carbohydrate content in the roots. In creeping bentgrass, mid-summer reductions in TNC in shoot and roots were related and proportional to the reduction of sugars and fructans (Xu and Huang 2003). The decline in carbohydrates during mid summer is due to decreased net photosynthesis and increased dark respiration (Carrow 1996; Huang and Gao 2000; Xu and Huang 2000b; Liu an Huang 2001). Watsche et al. (1972) reported a 47% reduction in net photosynthesis, and a 36%

reduction of TNC when cool-season grasses (*P. pratensis*, *P. trivialis* L., *P. compressa* L., and *Lolium perenne* L.) were placed in supra-optimal temperatures.

A possible basis for increased hybrid bluegrass heat tolerance is higher TNC accumulation and higher root densities. However, a literature search of hybrid bluegrass revealed no information on the allocation of TNC. The objectives of our experiment were to: 1) determine the status, allocation, and changes in nonstructural carbohydrates and 2) evaluate turfgrass performance of hybrid bluegrass, Kentucky bluegrass, supina bluegrass (*Poa supina* Shcrad.), and rough bluegrass (*Poa trivialis* L.) during heat stress.

MATERIAL AND METHODS

An experiment was conducted at two locations at the University of Tennessee in Knoxville, TN (35°49' N 83°59' W) during the summer of 2004. ‘Thermal Blue™’ hybrid bluegrass, ‘Apollo™’ Kentucky bluegrass, ‘Laser™’ rough bluegrass, and ‘Supranova™’ supina bluegrass were established in 50 by 40 cm rectangular pots that were 50 cm deep filled with 100% sand. Grasses were seeded at 100 kg/ha on December 12, 2003 in a greenhouse and 1 cm of irrigation was applied daily throughout the duration of the experiment. Grass was mowed twice per week at 25 mm and a soluble 20 N-8.8 P-16.6 K complete fertilizer was applied at 5 kg N/ha/wk. Grasses were moved on March 1, 2004 to two separate outside locations. Fungicide applications of thiophanate-methyl and iprodione were applied at 24 and 20 kg ai/ha, respectively, every 14 to 21 d starting the first week of June for disease control. Trials were arranged in a completely randomized design with 8 replications in the greenhouse and were re-randomized with 4 replications at each outdoor location. Both locations were in full sun and were with in 100 feet of the trees and buildings which restricted air movement.

On April 20, June 24, and July 28, 2004 three 8 cm^2 soil samples 50 cm deep were randomly taken from each pot. Each sample was separated into roots, crown area, and leaf tissue. Crown area was defined as the area from the top of the crowns (approximately 0.5 cm above the soil) to 1.3 cm below the soil surface. All plant samples were washed of sand in a gentle stream of water, combined with all other samples of that plant part from the same pot, packed in ice, and later frozen at -80 C with in 1.5 hr of sampling. Samples were then freeze dried at -25 C for one week and dry weights were recorded. Dried samples were finely ground using liquid nitrogen and a mortar and pestle and stored in desiccators at room temperature until analysis.

Carbohydrates were analyzed using procedures based upon the Hendrix (1993) method. Briefly, 100 mg of ground sample was placed with 2 ml of 80% ethanol in a glass test tube. The mixture was heated to 80 C for 15 min and liquid decanted. This process was repeated two more times. The decanted solutions were brought to a 10.0 ml volume. A 1.5 ml aliquot was added to 135 mg of activated charcoal and vortexed. The sample was centrifuged for 15 min and 20 µL aliquots were transferred with a pipette into 96 well plates and dried at 55 C for 24 hr. Twenty µL of deionized water was then added to each well. Glucose was determined by the addition of 100 µL of glucose assay reagent (Sigma GAHK-20[11]), fructose was determined by the addition of 10 µL phosphoglucose

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[11] Sigma-Aldrich Co., 3050 Spruce Street, St. Louis, MO 63103.

isomerase (Sigma P-9544), and sucrose was determined by the addition of 10 µL invertase (Sigma I-4504). Enzymes were added sequentially with a 15 min incubation time at 25 C in darkness and absorbencies were determined at 340 nm using a PowerWave XS[12] plate reader. The amounts of glucose, fructose, and sucrose were determined by using an external standard technique.

Starches were also determined by the Hendrix method (1993). Briefly, the remaining pellet from the sugar analysis was dried at 55 C for 12 hrs. Then 1 ml of 0.1 M KOH was added to the pellet and boiled for 1 hr and then cooled. This was followed with the addition of 0.2 ml of 1.0 M acetic acid. The sample was then adjusted to 7.2 pH with 0.1 M acetic acid. Samples were placed in a water bath at 80 C for 30 min with 360 enzyme units (EU) of dialyzed alpha-amylase (Sigma A-3403). Samples were cooled and pH was adjusted to 5.0 using 0.1 M acetic acid. Samples were placed in a 55 C water bath for 60 min with 122 EU of dialyzed amyloglucosidase (Sigma A-3042). Starch digestion was stopped by placing samples in a boiling water bath for 4 min. Samples were filled to a 6.0 ml volume and a 1.5 ml aliquot was added to 135 mg of activated charcoal and vortexed. The samples were centrifuged for 15 min and a 20 µL aliquot was transferred with a pipette into 96 well plates and dried at 55 C for 24 hr. Starch was determined by adding 20 µL of deionized water, 100 µL of glucose assay reagent (Sigma GAHK-20), and incubating for 15 min at 25 C in the darkness and reading absorbencies

[12] Bio-tek Instruments Inc., Highland Park, Box 998, Winooski, VT 05404-0998.

as previously described. The amounts of starch were determined by comparison to a glucose curve. TNC were determined by summing glucose, fructose, sucrose, and starch.

SAS (1999) Proc Mixed was utilized to perform analysis of variance for turfgrass glucose, fructose, sucrose, starch, TNC, and dry weights. All data were checked for equal variance and arcsine square root transformations were performed when necessary as determined by the Shapiro-Wilk statistic and untransformed means are presented for clarity. Main effects and all possible interactions were tested using appropriate expected mean square values as recommended by McIntosh (1983). There were no differences in the location or their interactions for any of the data, therefore all data will be pooled over locations. Grasses, months, and/or there interactions were significant for glucose, fructose, sucrose, starch, TNC, and dry weights in the leaves, crown area, and roots, therefore, all data were separated by grass and by month. Grasses, months, and there interactions were significant for TNC on a whole plant basis therefore data were separated by grass and by month. There were no differences in root depths, months, or there interaction. Means were separated using Fisher's Protected LSD at the 5% significance level and orthogonal polynomial contrasts were performed over months.

RESULTS AND DISCUSSION

Leaves. Glucose concentrations in the leaves were highest in April for all grasses with supina bluegrass having the highest concentration (Table 20). There were no differences in glucose in June or July among the grasses. Glucose amounts showed linear and quadratic trends with glucose being highest in April, lowest in June, and a slight increase in glucose in July.

Fructose concentrations in the leaves were similar to glucose (Table 20). Fructose concentrations in the leaves were highest in April for all grasses with supina bluegrass having the highest concentration. Hybrid bluegrass and Kentucky bluegrass showed slightly higher fructose amounts in June however these differences were nominal. There were no differences in fructose amounts in July for any of the grasses. Shoot fructose amounts showed linear and quadratic trends with fructose being highest in April and no differences in any of the grass leaves in June or July.

Sucrose concentrations in the leaves were much higher than glucose and fructose indicating that these grasses convert glucose and fructose into sucrose as an energy source (Table 20). Sucrose is well established as the transport sugar in higher plants and is expected to be in higher concentrations (Arnold 1968). Sucrose was highest in April with supina bluegrass having the highest concentration. In June, hybrid bluegrass and Kentucky bluegrass had the highest concentration of sucrose. There were no differences in sucrose amounts in any of the grasses in July. Shoot sucrose amounts showed mostly a linear decline with quadratic trends by all grasses. This was due to sucrose amounts being highest in April and no differences in any of the grass leaves in June or July.

Starch concentrations were highest in June with all grasses having relatively the same concentrations (Table 20). Starch amounts showed mostly quadratic trends with starch being the highest in June and lower amounts of starch in April and July. This was the opposite of fructose and sucrose, which showed linear declines from April to July.

TNC concentrations in the leaves were highest with supina bluegrass in April (Table 20). However, by June, supina bluegrass had the lowest TNC concentrations. All grasses showed linear declines in overall TNC. Only supina bluegrass had a quadratic trend, however June and July were not different. Hybrid bluegrass, Kentucky bluegrass, supina bluegrass, and rough bluegrass showed 65, 57, 67, and 42% less carbohydrates in July than in April, respectively, indicating an overall decrease in net carbohydrates in the shoot portion of all the grasses.

Crowns. Glucose concentrations in the crown area were highest in July for all grasses with Kentucky bluegrass having the highest concentration (Table 21). There were no differences in glucose in April and June for any of the grasses. Glucose was lowest in June for all grasses and caused quadratic trends from April to July. Rough bluegrass also showed a linear trend due to the increased glucose concentration in the crown area in July.

Fructose concentrations were similar to glucose concentrations in the crown area. Fructose concentrations in the crown area were lowest in June for all grass species (Table 21). Concentrations of fructose in the crown area were highly variable and no trends were readily observed. However, rough bluegrass showed both a linear and quadratic trend due to the increase in fructose in July.

Sucrose was highest in April for all grass species, with the exception of rough bluegrass which was the highest in July (Table 21). Hybrid bluegrass and Kentucky bluegrass sucrose concentrations in July were very low and below the detectable limits with the Hendrix method. Hybrid bluegrass, Kentucky bluegrass, and supina bluegrass all showed linear declines in crown area sucrose concentrations.

Starch concentrations were highest in July for all grasses with supina bluegrass and rough bluegrass having slightly higher concentrations than hybrid bluegrass and Kentucky bluegrass (Table 22). All grasses showed positive linear and quadratic trends with increasing starch concentration from April to July.

TNC concentrations in the crown area were highest in April for all grasses except rough bluegrass (Table 22). All grasses showed linear declines in overall TNC, with only supina bluegrass having quadratic tendencies. Hybrid bluegrass, Kentucky bluegrass, and supina bluegrass showed 50, 31, and 26% less carbohydrates in April than in July indicating an overall decrease in TNC in the crown area. However, rough bluegrass showed a 292% increase in TNC.

Roots. Glucose concentrations were < 5 mg/g and there were little differences in root glucose concentration in any of the grasses during any month (Table 22). Overall, glucose amounts were lower in the roots (Table 22) than in the leaves (Table 20) and crown area (Table 21).

Fructose concentrations were similar to glucose concentrations in the roots, < 5 mg/g, and there was little change from month to month (Table 22). Only Kentucky bluegrass had a linear increase in fructose concentration in the roots from April to July.

Sucrose concentrations were highest in June for all grass with hybrid bluegrass having the highest sucrose concentrations in the roots (Table 22). Hybrid bluegrass and Kentucky bluegrass showed linear and quadratic trends and supina bluegrass and rough bluegrass showed only quadratic trends in which June had the highest sucrose concentration.

Starch concentrations were similar for all grasses during each month (Table 22). All grasses, except Kentucky bluegrass, showed linear and quadratic increases in starch concentrations from April to July. Kentucky bluegrass starch concentrations were only quadratic due to decreased starch during June.

TNC concentrations in the root area were highest in June and July. However, hybrid bluegrass had the highest TNC concentration in June (Table 22). Supina and rough bluegrass had higher TNC levels during April. However, by July all grasses had similar TNC concentration in the roots. Hybrid bluegrass and Kentucky bluegrass showed linear increases in TNC concentrations. Hybrid bluegrass also displayed a quadratic trend in the TNC due to the June TNC concentrations. Hybrid bluegrass and Kentucky bluegrass showed 82 and 100% increases in TNC in the roots. This indicates that TNC from the leaves and crowns are being reallocated to the roots for storage.

Dry Weights. Supina bluegrass had higher shoot dry weights in April and June (Table 23). However by July there were no differences in shoot dry weights. Hybrid bluegrass and Kentucky bluegrass both showed linear increases in shoot dry weights from April to July. Kentucky bluegrass, as well as, supina bluegrass and rough bluegrass showed quadratic trends where little differences in April and July dry weights occurred but June was significantly higher.

Crown dry weights for all grasses were as follows for all months: Kentucky bluegrass $\geq$ hybrid bluegrass $\geq$ supina bluegrass $\geq$ rough bluegrass (Table 23). Crown dry weights were the same for each grass during each month sampled. However, Kentucky bluegrass showed a linear trend of increasing crown weight from April to July.

Root dry weights were highest for rough bluegrass in April (Table 23). However, rough bluegrass showed a decreasing trend and had lower dry weights in June and July than in April. All other grasses had the same root mass except Kentucky bluegrass which had a higher root mass in June than in April or July. In previous research, creeping bentgrass roots have been shown to have decreased TNC and decreased mass faster than shoots in the same high temperature environment (Xu and Huang 2000a, 2000b).

Whole Plant TNC Accumulation. Supina bluegrass had the highest amount of TNC accumulation in April (Table 24). However, there were no differences in TNC amounts for June or July. Hybrid bluegrass had a linear and quadratic trend that led to a total decrease in TNC from April to July. The TNC of Kentucky bluegrass and rough bluegrass were not different at any month. Supina bluegrass had a linear decrease in overall TNC accumulation.

Our hypothesis for this research was TNC accumulation would be highest for hybrid bluegrass > Kentucky bluegrass > rough bluegrass > supina bluegrass. This hypothesis was based on the geographical use of each grass and how Thermal Blue hybrid bluegrass is being marketed. However, Kentucky bluegrass had the greatest TNC accumulation over time, which may lead to increased heat tolerance (Table 24). However, further research is needed to determine if TNC accumulation is a main factor in increased heat tolerance.

Our research also indicated that Hybrid bluegrass and Kentucky bluegrass may have more heat tolerance due to a reallocation of TNC from the leaves in April to the roots in July. Also, decreased root weights of rough bluegrass may be attributed to higher temperatures. Carbohydrate allocation of these grasses may have been affected by the ideal growing conditions under which this research was conducted. The plants were never subjected to drought, disease stress, or lack of nutrients. Heat stress was limited by an unusually cool summer that was never >3 C above the maximum optimal temperature of 24 C suggested by Beard (1973) (Figure 8). During plant sampling it was visually noted that Kentucky bluegrass and hybrid bluegrass were the only species to have rhizomes. Rhizomes were located in the crown area and roots of the hybrid bluegrass and only in the crown area of Kentucky bluegrass. Bonos and Murphy (1999) saw that deeper rooted Kentucky bluegrass varieties were more heat tolerant. The increase in rooting depth was directly contributed to water use efficiency and transpiration cooling which was the underlying factor in summer performance of Kentucky bluegrass varieties. Also in previous research, drought preconditioning increased rooting which increased the heat tolerance of Kentucky bluegrass (Jiang and Huang 2001).

This research suggests that increased heat tolerance of Kentucky bluegrass and hybrid bluegrass may also be due to increased carbohydrate availability instead of decreased carbohydrate reserves. Previous research has shown decreased carbohydrate availability in creeping bentgrass and wheat during the summer (Al-Khatib and Paulsen 1989; Moffat et al. 1990; Liu and Huang 2000; Xu and Huang 2000a, 2000b; Liu and Huang 2001).

Turf breeders are constantly trying to develop new bluegrass species that are better adapted throughout the transition zone. In this research, hybrid bluegrass has no advantage in TNC accumulation over any of the other bluegrass species. This research suggests that bluegrass heat tolerance is probably tolerance to a complex of heat, drought, and other environmental stresses. Further investigation of TNC and there accumulation during times of stress is needed to determine if TNC is a good parameter to measure overall plant health.

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APPENDICES

APPENDIX A

TABLES

Table 1. Average percent brown patch incidence from May to August and average percent dollar spot incidence from June to October on five turfgrasses and three nitrogen regimes at two locations in Knoxville, TN in 2003 and 2004.

Turfgrass	Nitrogen	Brown Patch[a]	Dollar Spot[a]
	kg N/ha/yr	Disease Incidence (%)	
Apollo	50	0	20
	150	0	10
	300	0	7
Dura Blue	50	0	21
	150	0	12
	300	0	7
Thermal Blue	50	0	24
	150	0	17
	300	0	11
Dynasty	50	31	0
	150	22	0
	300	21	0
Kentucky 31	50	29	0
	150	23	0
	300	21	0
LSD[b] (0.05)		7	4

[a]Percent brown patch and dollar spot was visually estimated on a 0-100 scale with 0 being no dollar spot and 100 equaling dead turf.

[b]LSD- Least significant difference at the 5% probability level.

Table 2. Single degree of freedom contrast analysis Thermal Blue percent turf cover in 2003 and 2004 and seeding rate quality in 2003 in Knoxville, TN.

	2	3	5	7	9	10	11
	Months after seeding						
Cover							
50 vs. 100	ns	ns	ns	ns	ns	ns	ns
100 vs. 150	0.005	ns	ns	ns	ns	ns	ns
50 and 100 vs. 150, 200, and 250	0.0001	0.01	ns	ns	ns	ns	ns
150 vs. 200 and 250	ns	ns	ns	ns	ns	ns	ns
Quality 2003							
50 vs. 100	ns	ns	ns	0.01	0.0005	ns	ns
100 vs. 150	0.007	ns	ns	0.01	ns	ns	ns
50 and 100 vs. 150, 200, and 250	0.0001	0.001	0.001	0.0001	0.003	ns	ns
150 vs. 200 and 250	ns	ns	ns	ns	ns	ns	ns

Table 3. Analysis of variance of quality for fertility and mowing height regimes on Thermal Blue and Dura Blue in Knoxville, TN in 2004 and 2005.

	DF	Overall	April	July	October
		Pr>F[a]			
Cultivar (C)	1	0.0004	0.0001	ns	ns
Fertility (F)	4	ns	0.0005	ns	0.02
C*F	4	ns	ns	ns	ns
Mowing Height (H)	2	ns	0.0001	0.0001	0.006
C*H	2	ns	ns	ns	ns
F*H	8	ns	ns	ns	ns
C*F*H	8	ns	ns	ns	ns
Month (M)	2	0.0001			
M*C	2	0.001			
M*F	8	ns			
M*H	4	0.01			
M*C*F*H	16	ns			
Year (Y)	1	ns	ns	ns	ns
Y*C	1	ns	ns	ns	ns
Y*F	4	ns	ns	ns	ns
Y*H	2	ns	ns	ns	ns
Y*C*F*H	8	ns	ns	ns	ns
Y*M*C*F*H	8	0.0001			

Table 4. Thermal Blue and Dura Blue turf quality and dry weights pooled over fertility, mowing heights, and years in Knoxville, TN in 2004 and 2005.

Cultivar	April	July	October
	Quality (1-9)		
Dura Blue	7.7	7.6	6.4
Thermal Blue	8.1	7.6	6.4
LSD[a] (0.05)	0.1	ns	ns
	Dry Weight (kg/ha)		
Dura Blue	78	143	53
Thermal Blue	117	170	51
LSD[a] (0.05)	7	ns	ns

[a]LSD- Least significant difference at the 5% probability level.

Table 5. Analysis of variance of biomass for fertility and mowing height regimes on Thermal Blue and Dura Blue in Knoxville, TN in 2004 and 2005.

	DF	Overall	April	July	October
		Pr>F[a]			
Cultivar (C)	1	0.0001	0.0001	ns	ns
Fertility (F)	4	ns	ns	ns	ns
C*F	4	ns	ns	ns	ns
Mowing Height (H)	2	ns	0.0001	ns	ns
C*H	2	ns	ns	ns	ns
F*H	8	ns	ns	ns	ns
C*F*H	8	ns	ns	ns	ns
Month (M)	2	ns			
M*C	2	0.0001			
M*F	8	ns			
M*H	4	0.0001			
M*C*F*H	16	ns			
Year (Y)	1	ns	ns	ns	ns
Y*C	1	ns	ns	ns	ns
Y*F	4	ns	ns	ns	ns
Y*H	2	ns	ns	ns	ns
Y*C*F*H	8	ns	ns	ns	ns
Y*M*C*F*H	8	ns			

Table 6. Thermal Blue and Dura Blue turf quality and dry weights for fertility regimes pooled over cultivar, mowing height, and years in Knoxville, TN in 2004 and 2005.

Fertility	kg N/ha	April	July	October
		Quality (1-9)		
Ammonium nitrate	100	7.8	7.7	6.6
Ammonium nitrate	200	8	7.6	6.3
Ammonium nitrate	300	8.1	7.5	5.9
Urea formaldehyde	200	7.7	7.6	6.6
Urea formaldehyde	300	7.8	7.5	6.4
LSD[a] (0.05)		0.2	ns	0.4
		Dry Weight (kg/ha)		
Ammonium nitrate	100	90	149	51
Ammonium nitrate	200	104	160	52
Ammonium nitrate	300	109	166	50
Urea formaldehyde	200	91	150	52
Urea formaldehyde	300	95	155	58
LSD[a] (0.05)		ns	ns	ns

[a]LSD- Least significant difference at the 5% probability level.

Table 7. Thermal Blue and Dura Blue turf quality and dry weights for mowing heights of 2, 3.5, and 50 mm mowing heights pooled over cultivar, fertility, and years in Knoxville, TN in 2004 and 2005.

Mowing Height (mm)	April	July	October
	Quality (1-9)		
20	7.6	7.1	5.1
35	7.9	7.8	6.8
50	8	7.9	7.3
LSD[a] (0.05)	0.2	0.2	0.3
	Dry Weights (kg/ha)		
20	128	176	55
35	85	163	52
50	81	129	50
LSD[a] (0.05)	6	ns	ns

[a]LSD- Least significant difference at the 5% probability level.

Table 8. Analysis of variance for Thermal Blue under varying plant growth regulators regimes in Knoxville, TN in 2004 and 2005.

Source	DF	Color	Quality	Injury	Dry Weight
		Pr>F[a]			
PGR (P)	6	***	***	***	***
Month (M)	2	***	*	***	***
P*M	12	***	***	***	**
Year (Y)	1	ns	***	ns	*
P*Y	6	***	***	***	ns
M*Y	2	***	***	***	ns
P*M*Y	12	***	***	***	ns

[a]*, **, *** Significant at the 0.05, 0.01, and 0.001 probability level.

Table 9. Analysis of variance for Thermal Blue under varying plant growth regulators and mowing height regimes in Knoxville, TN in 2004 and 2005.

Source	DF	Color	Quality	Dry Weight
			Pr>F[a]	
Treatment (T)	3	***	ns	***
Mowing Height (H)	2	***	ns	***
T * H	6	***	***	ns
Month (M)	5	***	ns	***
T*M	15	***	***	*
H*M	10	*	***	***
T*H*M	30	***	***	ns
Year (Y)	1	ns	ns	ns
T*Y	3	ns	ns	ns
H*Y	2	ns	ns	ns
M*Y	5	ns	ns	ns
T*H*Y	6	ns	ns	ns
T*H*M*Y	30	ns	ns	ns

[a] *, **, *** Significant at the 0.05, 0.01, and 0.001 probability level.

Table 10. Thermal Blue injury 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

	Rate		2004			2005	
Treatment	g ai/ha	June	July	August	June	July	August
		——	——	——	% Injury	——	——
Untreated	-	0	0	0	0	0	0
Ethephon	3800	0	1	0	0	1	1
	7600	0	2	4	0	1	1
Paclobutrazol	570	0	5	0	0	19	4
	1100	0	14	30	0	20	15
Trinexepac-ethyl	230	0	3	0	0	8	0
	460	0	5	0	0	8	0
LSD[a] (0.05)		ns	4	1	ns	7	2

[a]LSD- Least significant difference at the 5% probability level.

Table 11. Thermal Blue color 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

	Rate	2004			2005		
Treatment	g ai/ha	June	July	August	June	July	August
		Color (1-9)					
Untreated	-	8.0	8.0	8.0	7.9	7.0	7.3
Ethephon	3800	7.3	7.8	7.8	8.0	8.0	7.3
	7600	7.3	8.0	7.5	8.0	8.0	6.8
Paclobutrazol	570	8.0	7.3	8.0	8.0	6.0	8.7
	1100	8.0	6.0	5.0	8.1	6.5	7.0
Trinexepac-ethyl	230	7.9	7.8	8.0	8.0	6.8	8.0
	460	7.4	7.0	8.0	7.8	7.5	8.0
LSD[a] (0.05)		0.5	0.5	0.6	ns	0.8	0.6

[a]LSD- Least significant difference at the 5% probability level.

Table 12. Thermal Blue quality 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

Treatment	Rate g ai/ha	2004 June	2004 July	2004 August	2005 June	2005 July	2005 August
		Quality (1-9)					
Untreated	-	8.0	8.0	8.0	7.0	7.3	8.0
Ethephon	3800	7.6	7.8	7.3	7.8	7.0	6.6
	7600	7.6	7.5	7.0	7.8	6.8	5.0
Paclobutrazol	570	7.9	7.1	7.0	6.0	7.3	8.3
	1100	7.8	6.0	5.0	6.5	5.8	7.1
Trinexepac-ethyl	230	8.0	7.5	8.0	6.8	8.0	8.5
	460	7.6	7.0	8.0	7.5	8.0	8.4
LSD[a] (0.05)		ns	0.6	0.3	0.9	0.6	0.7

[a]LSD- Least significant difference at the 5% probability level.

Table 13. Thermal Blue clipping dry weights 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

	Rate		2004			2005	
Treatment	g ai/ha	June	July	August	June	July	August
		Dry Weights (kg/ha)					
Untreated	-	.	323	243	452	297	301
Ethephon	3800	.	245	265	342	243	238
	7600	.	258	247	317	305	281
Paclobutrazol	570	.	156	123	365	168	192
	1100	.	80	34	286	138	141
Trinexepac-ethyl	230	.	218	270	388	249	290
	460	.	256	307	296	251	278
LSD[a] (0.05)		.	100	68	ns	64	64

[a]LSD- Least significant difference at the 5% probability level.

Table 14. Thermal Blue color 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

Treatment	Rate	Height	June	July	Aug	Sept	Oct	Nov
	g ai/ha	mm	Color (1-9)					
Untreated	-	20	7.2	6.7	8.0	5.8	7.2	7.0
		35	7.4	6.9	8.0	6.5	7.5	7.1
		50	7.5	7.2	8.3	6.9	7.4	7.3
Ethephon	3800	20	7.8	6.0	2.6	2.3	2.8	2.8
		35	7.9	6.8	7.9	3.9	4.2	4.6
		50	7.9	7.3	8.0	4.9	6.4	6.4
Paclobutrazol	280	20	8.0	7.7	8.3	6.4	8.1	8.4
		35	8.0	7.7	8.3	7.4	8.3	7.7
		50	8.1	7.7	8.3	7.4	8.3	8.6
Trinexepac-ethyl	230	20	7.6	6.6	8.1	5.7	7.4	7.8
		35	7.7	7.0	8.4	7.1	7.7	7.8
		50	7.7	7.3	8.4	7.4	7.2	7.7
LSD_1[a] (0.05)			0.4	0.6	0.6	1.6	1.2	1.2
LSD_2[b] (0.05)			0.5	0.7	0.6	1.6	1.2	1.2

[a]LSD_1- Least significant difference of mowing heights within each treatment at the 5% probability level.

[b]LSD_2- Least significant difference of treatment within each mowing height a the 5% probability level.

Table 15. Thermal Blue quality 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

Treatment	Rate	Height	June	July	Aug	Sept	Oct	Nov
	g ai/ha	mm	Quality (1-9)					
Untreated	-	20	7.1	6.7	7.4	4.2	6.5	6.4
		35	7.4	7.1	8.0	6.0	7.5	6.8
		50	7.5	7.2	8.0	6.5	7.4	6.9
Ethephon	3800	20	7.8	6.0	2.6	1.0	3.0	3.9
		35	7.9	6.8	6.7	1.8	4.0	5.0
		50	7.9	7.4	7.0	3.5	5.6	6.1
Paclobutrazol	280	20	8.0	7.7	7.7	4.8	7.3	7.0
		35	7.9	7.7	8.0	6.6	8.0	7.5
		50	8.0	7.7	8.0	7.0	7.8	7.4
Trinexepac-ethyl	230	20	7.3	6.6	6.4	4.8	6.8	6.8
		35	7.3	7.1	8.0	6.6	7.6	7.4
		50	7.5	7.1	8.0	7.3	7.7	7.4
LSD_1[a] (0.05)			0.4	0.6	0.4	1.1	1.5	1.3
LSD_2[b] (0.05)			0.4	0.7	0.4	1.1	1.5	1.3

[a]LSD_1- Least significant difference of mowing heights within each treatment at the 5% probability level.

[b]LSD_2- Least significant difference of treatment within each mowing height a the 5% probability level.

Table 16. Thermal Blue dry weights 15 days after plant growth regulator applications in Knoxville, TN in 2004 and 2005.

Treatment	Rate	Height	June	July	Aug	Sept	Oct	Nov
	g ai/ha	mm	Dry Weight (kg/ha)					
Untreated	-	20	163	117	137	78	59	59
		35	137	137	111	65	59	52
		50	111	85	91	52	46	46
Ethephon	3800	20	183	124	78	13	33	33
		35	104	98	98	13	20	26
		50	72	72	78	15	26	26
Paclobutrazol	280	20	163	150	150	39	65	59
		35	143	137	111	26	52	46
		50	104	85	85	20	33	26
Trinexepac-ethyl	230	20	150	104	137	52	59	46
		35	104	143	104	39	65	39
		50	85	85	91	26	46	39
LSD_1[a] (0.05)			34	59	28	20	ns	ns
LSD_2[b] (0.05)			47	52	25	19	ns	ns

[a]LSD_1- Least significant difference of mowing heights within each treatment at the 5% probability level.

[b]LSD_2- Least significant difference of treatment within each mowing height a the 5% probability level.

Table 17. Thermal Blue response to preemergence herbicides applied at seeding when evaluated 5 and 25 wk after treatment in Knoxville, TN from 2003 to 2005.

PRE Herbicide(s)	Rate	5 WAT	25 WAT	5 WAT	25 WAT
	g ai/ha	% Cover		% Injury	
Dithiopyr	560	0	1	99	99
Oryzalin	1680	0	0	100	100
Oxadiazon	1680	0	0	100	100
Pendimethalin	2240	0	0	100	100
Prodiamine	1120	2	3	99	98
Quinclorac	840	4	20	96	81
Trifluralin	1120	2	4	99	97
Untreated	--	40	77	0	0
LSD[a] (0.05)		15	18	2	16

[a]LSD- Least significant difference at the 5% probability level.

Table 18. Thermal Blue hybrid bluegrass quality, injury, and chlorophyll index when treated with postemergence applied ALS herbicides in Knoxville, TN in 2004 and 2005.

Herbicide		2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT
	g ai/ha	% Injury			Quality (0-9)			Chlorophyll Meter Index[a]		
Bispyribac-sodium	148	6	1	0	6.9	7.6	8	85	102	98
Bispyribac-sodium	296	6	4	1	6.9	7.3	7.9	83	98	94
Chlorosulfuron	278	1	0	0	7.4	7.8	7.9	101	102	94
Chlorosulfuron	557	1	0	0	7.4	7.8	8	98	102	91
Foramsulfuron	44	6	13	0	7	6.3	8.1	82	82	101
Foramsulfuron	88	7	36	2	6.8	4.9	7.4	84	70	101
Halosulfuron	68	1	1	1	7.4	7.6	7.8	96	99	92
Halosulfuron	137	0	0	0	7.5	7.8	7.9	99	102	96
Imazapic	105	3	0	0	7.3	7.8	8	90	104	93
Imazapic	210	4	4	1	7.1	7.3	7.9	89	105	96
Imazaquin	560	4	0	1	7.1	7.8	7.9	94	107	94
Imazaquin	1120	4	1	1	7.1	7.6	7.8	93	105	96

Table 18. Continued.

		2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT
	g ai/ha	% Injury			Quality (0-9)			Chlorophyll Meter Index[a]		
Metsulfuron-methyl	42	1	0	1	7.4	7.8	7.9	99	102	90
Metsulfuron-methyl	84	2	1	1	7.4	7.5	7.6	94	102	88
Rimsulfuron	35	6	3	0	6.9	7.6	8	85	101	98
Rimsulfuron	70	5	3	1	7	7.7	7.9	82	104	102
Sulfosulfuron	53	1	1	0	7.4	7.5	8	96	108	94
Sulfosulfuron	105	3	2	1	7.3	7.5	7.6	90	106	94
Trifloxysulfuron	17	5	6	1	7	7.2	7.7	84	92	101
Trifloxysulfuron	35	6	26	7	6.9	5.3	6.9	82	79	101
Untreated	--	0	0	0	7.4	7.8	7.9	100	100	100
LSD[b] (0.05)		ns	8	2	ns	0.5	0.5	9	18	ns

[a]Chlorophyll meter indices were normalized to percentages based on the untreated control plots. Chlorophyll meter indices for the untreated plots were 381 2 WAT, 291 5 WAT, and 268 10 WAT.

[b]LSD- Least significant difference at the 5% probability level.

Table 19. Thermal Blue hybrid bluegrass quality, injury, and chlorophyll index when treated with postemergence applied graminicides in Knoxville, TN in 2004 and 2005.

	Rate	2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT
	g ai/ha	—% Injury—			—Quality (1-9)—			—% Chlorophyll Meter Index[a]—		
Clethodim	140	12	12	2	6.4	6.5	7.8	82	82	98
Clethodim	280	11	32	8	6.4	4.9	6.9	84	76	97
Clethodim	560	15	53	14	6.3	3.6	6.5	79	63	89
Diclofop-methyl	570	1	2	1	7.5	7.4	7.8	98	95	98
Diclofop-methyl	1140	0	2	0	7.6	7.5	8.0	98	92	100
Diclofop-methyl	2290	1	1	3	7.4	7.6	7.6	96	94	100
Fluazifop-p-butyl	105	8	3	2	6.9	7.4	7.6	93	96	105
Fluazifop-p-butyl	210	9	11	1	6.8	6.6	7.9	84	89	106
Fluazifop-p-butyl	420	11	44	7	6.6	4.3	7.0	84	70	95
Sethoxydim	160	8	4	3	6.8	6.8	7.6	87	90	104

Table 19. Continued

	Rate	2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT	2 WAT	5 WAT	10 WAT
	g ai/ha	% Injury			Quality (1-9)			% Chlorophyll Meter Index[a]		
Sethoxydim	320	11	12	3	6.6	6.1	7.6	83	86	104
Sethoxydim	630	12	36	9	6.5	4.6	6.9	82	75	98
Untreated	--	0	0	0	7.6	7.8	7.5	100	100	100
LSD[b] (0.05)		4	19	7	0.4	1.4	ns	12	31	8

[a]Chlorophyll meter indices were normalized to percentages based on the untreated control plots. Chlorophyll meter indices for the untreated plots were 353 2 WAT, 261 5 WAT, and 256 10 WAT.

[b]LSD- Least significant difference at the 5% probability level.

Table 20. Glucose, fructose, sucrose, starch, and total nonstructural carbohydrate accumulation in the leaves of hybrid bluegrass (HBG), Kentucky bluegrass (KBG), rough bluegrass (RB), and supina bluegrass (SB) in Knoxville, TN in 2004.

	April	June	July	LSD[b] (0.05)	Linear [a]	Quadratic [a]
	———mg carbohydrate/g dry weight——					
Glucose						
HBG	11	4	7	3	***	***
KBG	15	3	9	3	***	***
SB	24	2	7	4	***	***
RB	11	3	8	4	*	**
LSD[b] (0.05)	4	ns	ns			
Fructose						
HBG	11	4	4	2	***	*
KBG	13	4	4	2	***	**
SB	26	2	5	5	***	***
RB	8	2	4	3	***	**
LSD[b] (0.05)	5	1	ns			
Sucrose						
HBG	118	34	23	17	***	**
KBG	125	40	35	22	***	**
SB	175	13	31	33	***	***
RB	100	25	42	29	***	***
LSD[b] (0.05)	32	14	ns			

Table 20. Continued

	April	June	July	LSD[b] (0.05)	Linear [a]	Quadratic [a]
	———mg carbohydrate/g dry weight——					
Starch						
HBG	42	56	29	9	*	***
KBG	40	52	30	8	ns	***
SB	39	52	42	6	ns	***
RB	38	54	33	9	ns	***
LSD[b] (0.05)	ns	ns	5	7		
TNC						
HBG	182	97	62	23	***	ns
KBG	188	99	80	27	***	ns
SB	263	70	87	46	***	**
RB	158	84	91	37	***	ns
LSD[b] (0.05)	40	19	ns			

[a] *, **, *** represent 0.05, 0.01, and 0.001 levels of significance.

[b]LSD- Least significant difference at the 5% probability level.

Table 21. Glucose, fructose, sucrose, starch, and total nonstructural carbohydrate accumulation in the crown area of hybrid bluegrass (HBG), Kentucky bluegrass (KBG), rough bluegrass (RB), and supina bluegrass (SB) in Knoxville, TN in 2004.

	April	June	July	LSD (0.05)	Linear[a]	Quadratic[a]
	——mg carbohydrate/g dry weight——					
Glucose						
HBG	5	1	5	2	ns	**
KBG	5	1	10	5	ns	**
SB	4	1	5	2	ns	**
RB	3	2	6	1	***	***
LSD[b] (0.05)	ns	ns	4			
Fructose						
HBG	3	1	3	1	ns	**
KBG	2	1	1	ns	**	ns
SB	5	2	3	ns	ns	ns
RB	1	1	7	2	***	***
LSD[b] (0.05)	3	ns	3			
Sucrose						
HBG	57	13	0	17	***	ns
KBG	44	9	0	13	***	ns
SB	59	12	10	20	***	ns
RB	11	17	47	12	***	**
LSD[b] (0.05)	24	5	11			

Table 21. Continued

	April	June	July	LSD (0.05)	Linear[a]	Quadratic[a]
	———mg carbohydrate/g dry weight——					
Starch						
HBG	3	3	27	9	***	***
KBG	2	2	26	9	***	***
SB	5	4	37	3	***	***
RB	8	8	38	7	***	***
LSD[b] (0.05)	3	2	9			
TNC						
HBG	69	18	35	27	**	***
KBG	54	13	37	21	*	**
SB	74	20	55	25	*	***
RB	25	28	98	16	***	***
LSD[b] (0.05)	27	ns	12			

[a] *, **, *** represent 0.05, 0.01, and 0.001 levels of significance.

[b]LSD- Least significant difference at the 5% probability level.

Table 22. Glucose, fructose, sucrose, starch, and total nonstructural carbohydrate accumulation in the roots of hybrid bluegrass (HBG), Kentucky bluegrass (KBG), rough bluegrass (RB), and supina bluegrass (SB) in Knoxville, TN in 2004.

	April	June	July	LSD[b] (0.05)	Linear[a]	Quadratic[a]
	———mg carbohydrate/g dry weight——					
Glucose						
HBG	2	4	2	1	ns	***
KBG	2	3	3	ns	ns	ns
SB	4	3	2	ns	*	ns
RB	4	3	2	ns	*	ns
LSD[b] (0.05)	ns	ns	ns			
Fructose						
HBG	2	3	2	ns	ns	ns
KBG	1	2	4	2	**	ns
SB	5	3	3	ns	ns	ns
RB	3	2	2	ns	ns	ns
LSD[b] (0.05)	2	ns	ns			
Sucrose						
HBG	11	87	33	26	**	**
KBG	6	46	29	26	*	*
SB	25	48	24	ns	ns	*
RB	28	37	12	19	ns	*
LSD[b] (0.05)	15	28	ns			

Table 22. Continued.

	April	June	July	LSD[b] (0.05)	Linear[a]	Quadratic[a]
	——mg carbohydrate/g dry weight——					
Starch						
HBG	32	30	49	6	***	***
KBG	41	29	50	13	ns	**
SB	32	29	52	8	***	***
RB	32	33	51	11	**	**
LSD[b] (0.05)	ns	ns	ns			
TNC						
HBG	47	123	86	31	**	***
KBG	46	83	92	34	**	ns
SB	66	82	81	ns	ns	ns
RB	69	77	72	ns	ns	ns
LSD[b] (0.05)	21	35	ns			

[a] *, **, *** represent 0.05, 0.01, and 0.001 levels of significance.

[b]LSD- Least significant difference at the 5% probability level.

Table 23. Hybrid bluegrass (HBG), Kentucky bluegrass (KBG), rough bluegrass (RB), and supina bluegrass (SB) shoot, crown, and root dry weights in Knoxville, TN in 2004.

	April	June	July	LSD[b] (0.05)	Linear[a]	Quadratic[a]
	——Dry Weight (kg/m^2)——					
Leaves						
HBG	1.6	3.0	3.3	0.8	***	ns
KBG	1.9	4.4	3.4	1.4	**	**
SB	2.5	7.8	2.5	2.1	ns	***
RB	2.0	5.3	2.5	2.0	ns	***
LSD[b] (0.05)	0.5	2.3	ns			
Crowns						
HBG	12.1	14.1	16.8	ns	ns	ns
KBG	18.0	19.9	24.0	ns	*	ns
SB	10.1	10.6	13.1	ns	ns	ns
RB	6.4	7.0	7.3	ns	ns	ns
LSD[b] (0.05)	3.6	4.1	5.8			

Table 23. Continued.

	April	June	July	LSD[b] (0.05)	Linear[a]	Quadratic[a]
	——Dry Weight (kg/m^2)——					
Roots						
HBG	1.6	1.6	1.6	ns	ns	ns
KBG	1.4	2.3	1.6	0.5	ns	**
SB	1.3	2.0	1.3	ns	ns	ns
RB	2.3	1.1	0.8	0.8	***	ns
LSD[b] (0.05)	0.5	ns	0.5			

[a] *, **, *** represent 0.05, 0.01, and 0.001 levels of significance.

[b]LSD- Least significant difference at the 5% probability level.

Table 24. Whole plant total nonstructural carbohydrate accumulations over one square meter of Hybrid bluegrass (HBG), Kentucky bluegrass (KBG), rough bluegrass (RB), and supina bluegrass (SB) in Knoxville, TN in 2004.

Whole Plant	April	June	July	LSD[b] (0.05)	Linear [a]	Quadratic [a]
	————	kg TNC/ m^2	————			
HBG	1.2	0.7	0.8	0.2	**	*
KBG	1.0	0.9	1.3	ns	ns	ns
SB	1.5	0.7	0.9	0.7	*	ns
RB	0.6	0.7	0.9	ns	*	ns
LSD[b] (0.05)	0.4	ns	ns			

[a] *, **, *** represent 0.05, 0.01, and 0.001 levels of significance.

[b]LSD- Least significant difference at the 5% probability level.

APPENDIX B

FIGURES

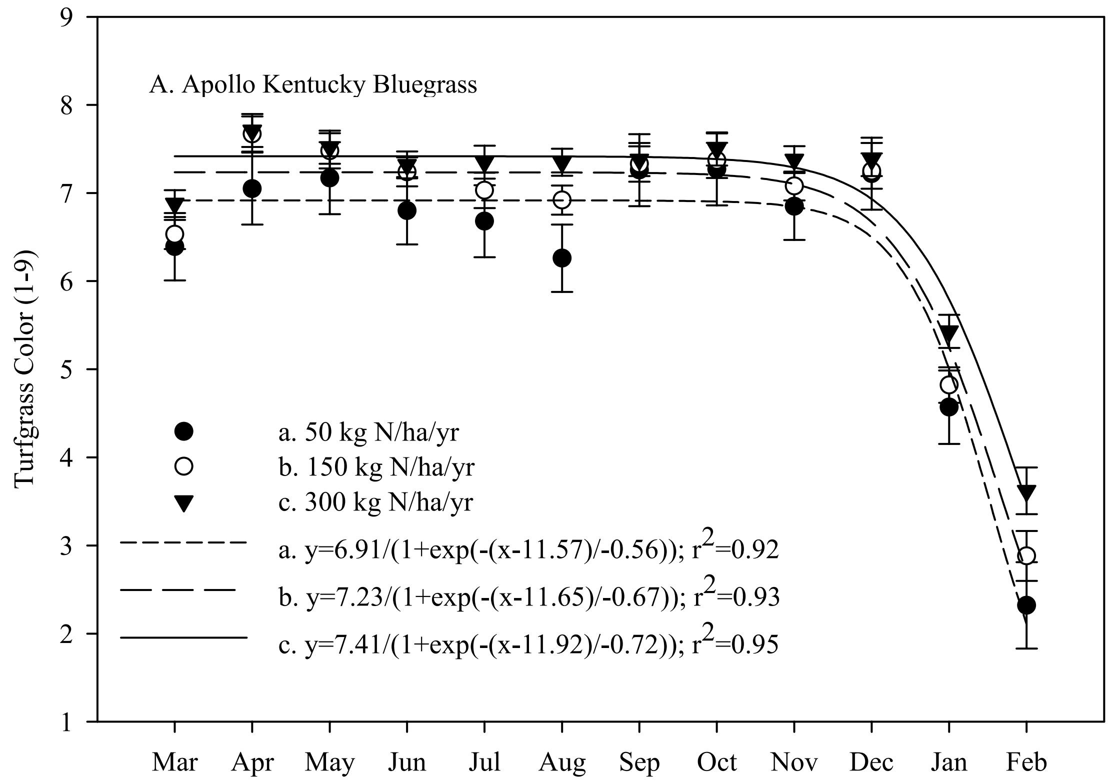

Figure 1. Turfgrass color regression analysis using a logistic model for the comparison of Apollo (A), Dura Blue (B), Thermal Blue (C), Dynasty (D), and Kentucky 31 (E) at 50, 150, and 300 kg N/ha/ yr.

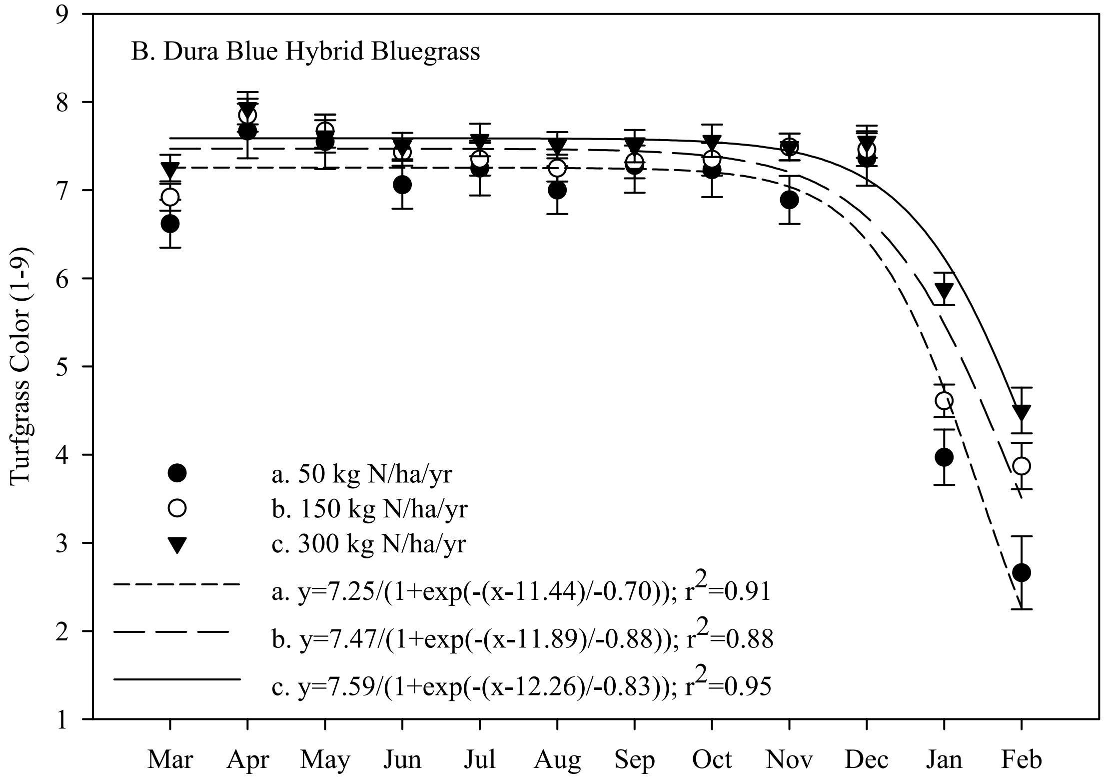

Figure 1. Continued.

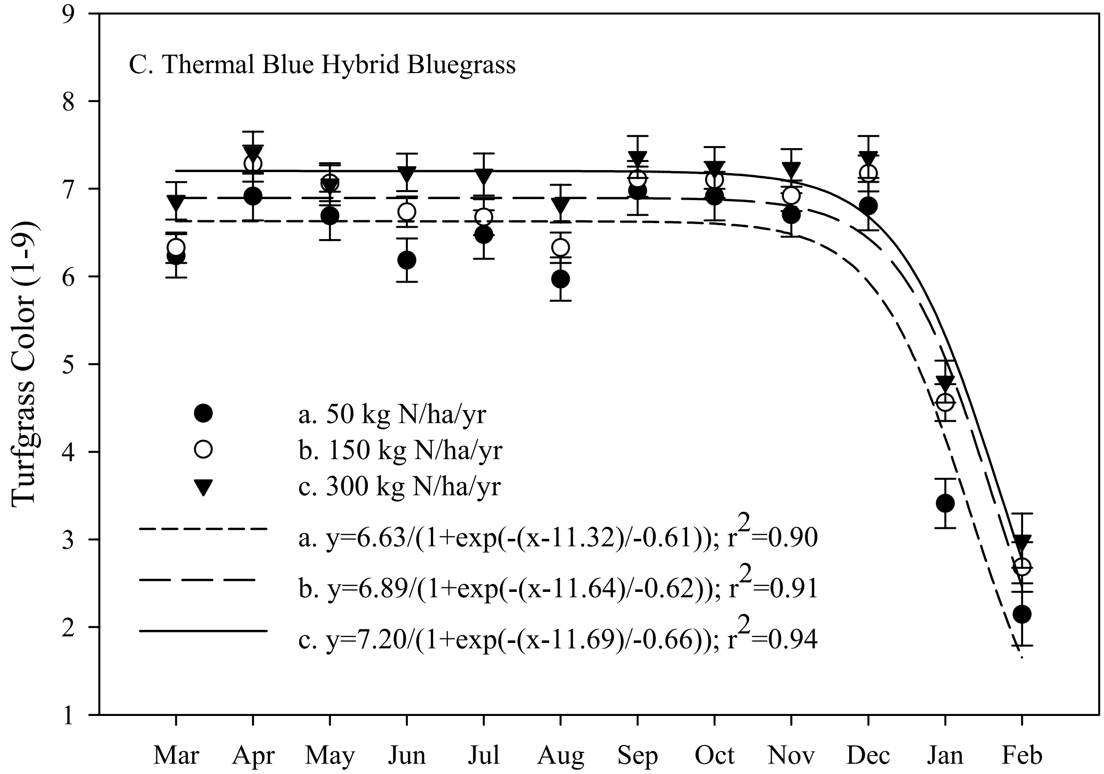

Figure 1. Continued.

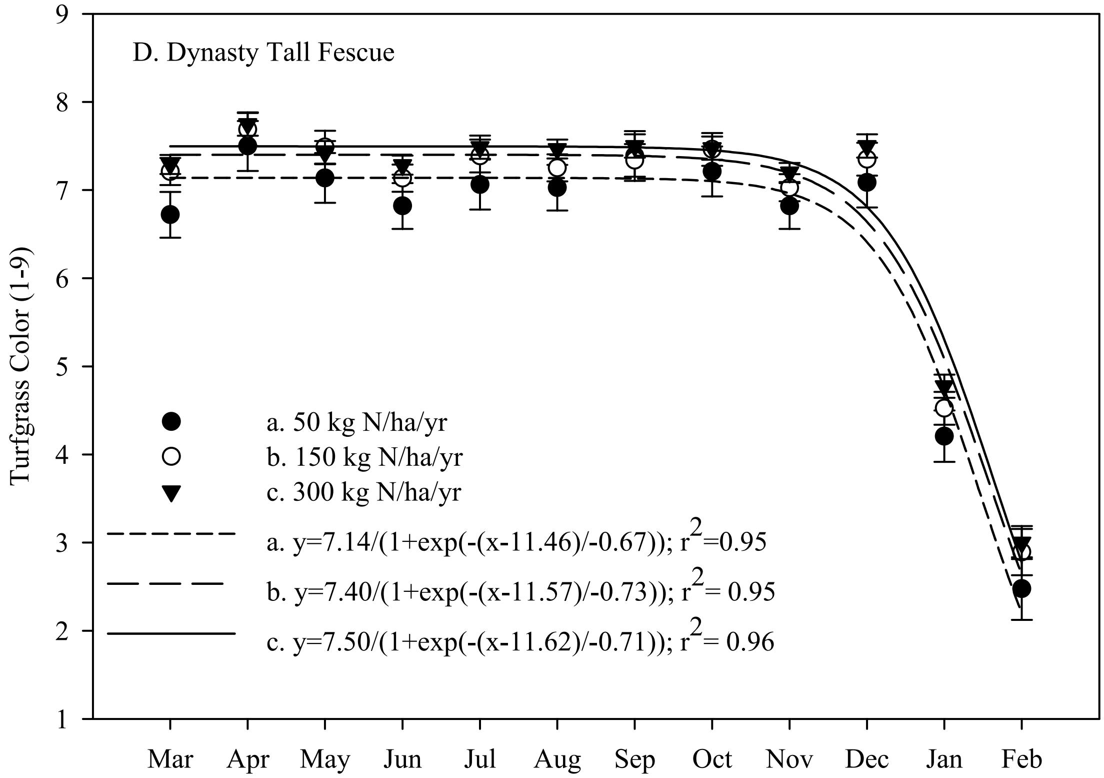

Figure 1. Continued.

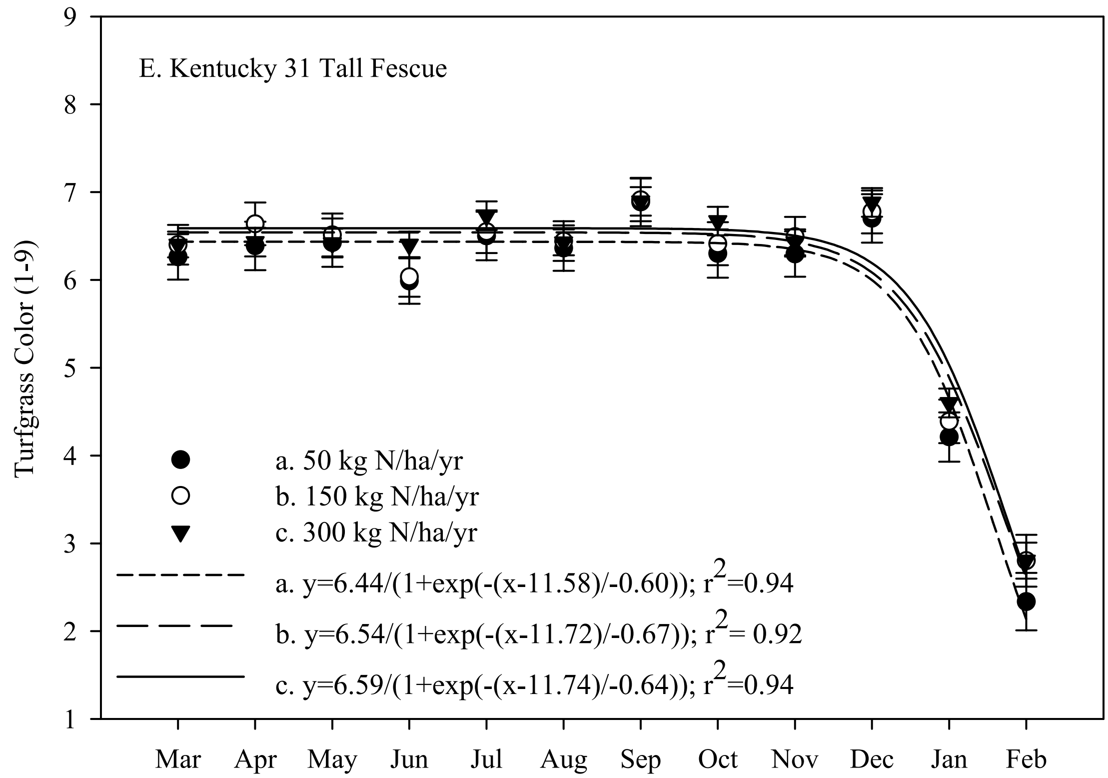

Figure 1. Continued.

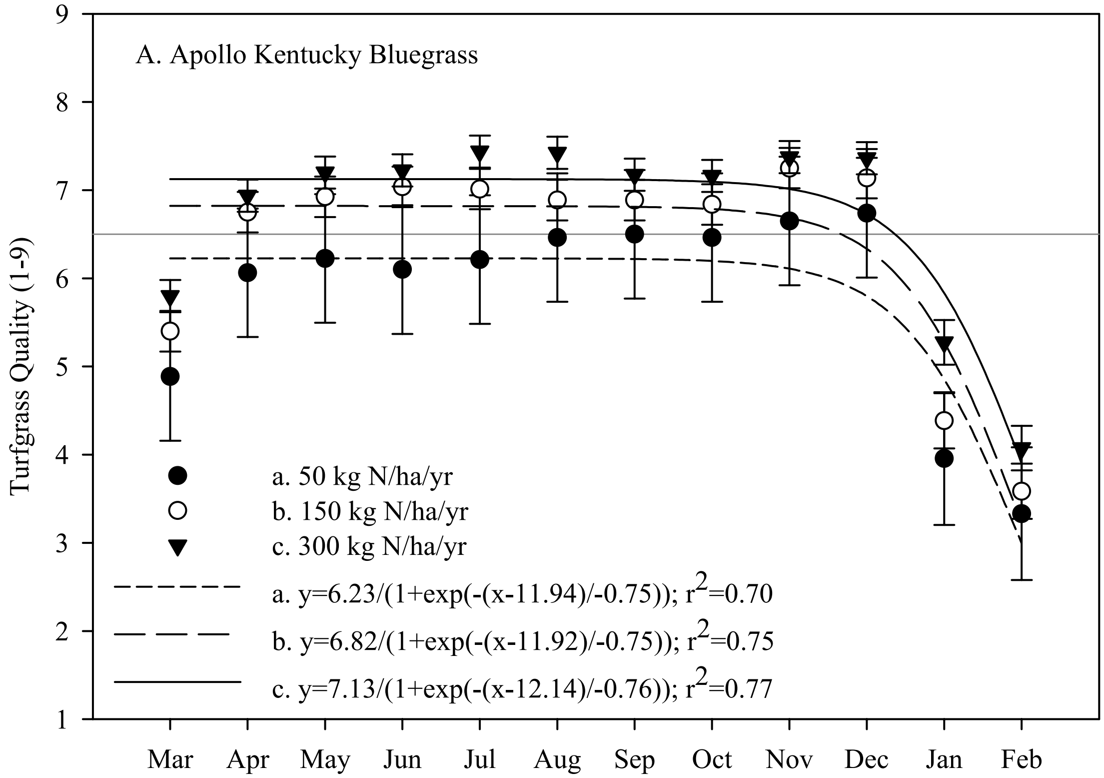

Figure 2. Turfgrass quality regression analysis using a logistic model for the comparison of Apollo (A), Dura Blue (B), Thermal Blue (C), Dynasty (D), and Kentucky 31 (E) at 50, 150, and 300 kg N/ha/yr. Dotted horizontal line at 6.5 indicates minimum acceptable turfgrass quality.

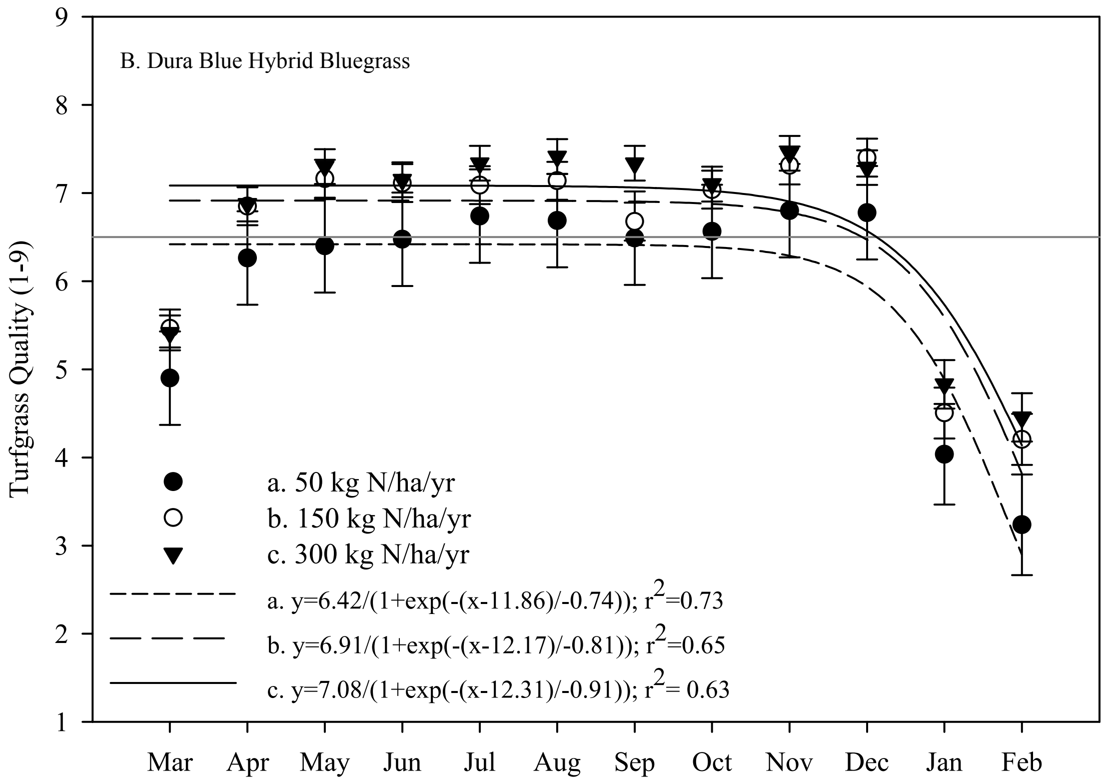

Figure 2. Continued.

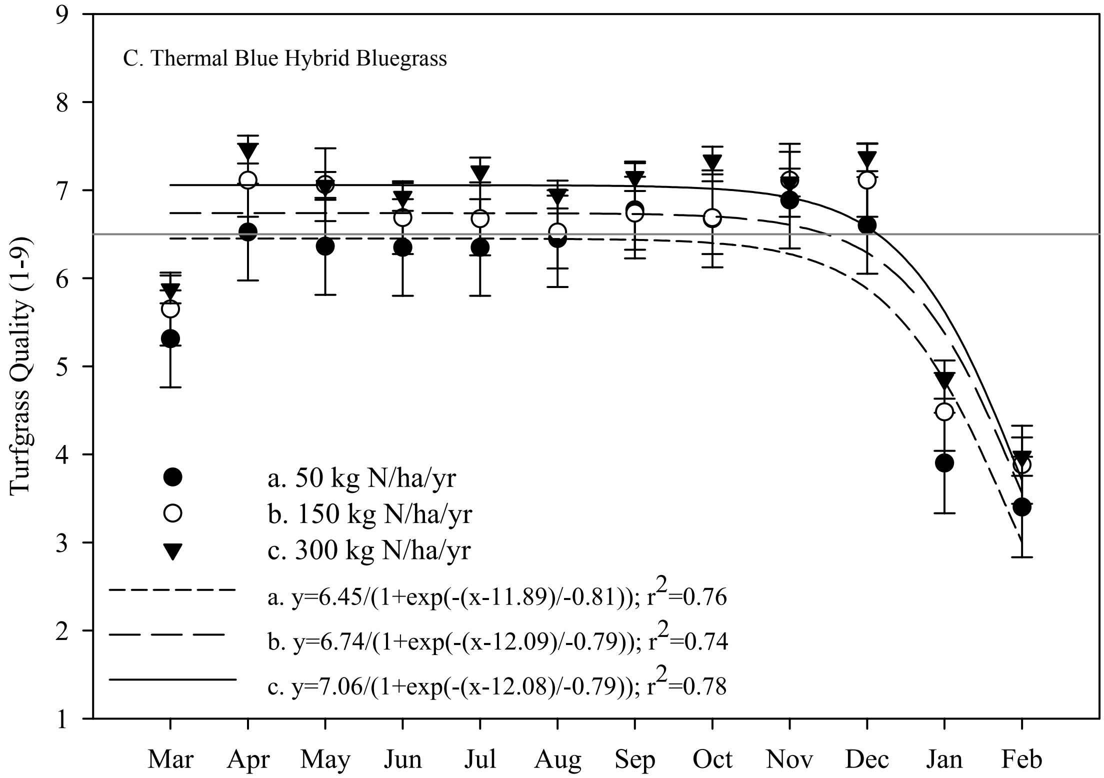

Figure 2. Continued.

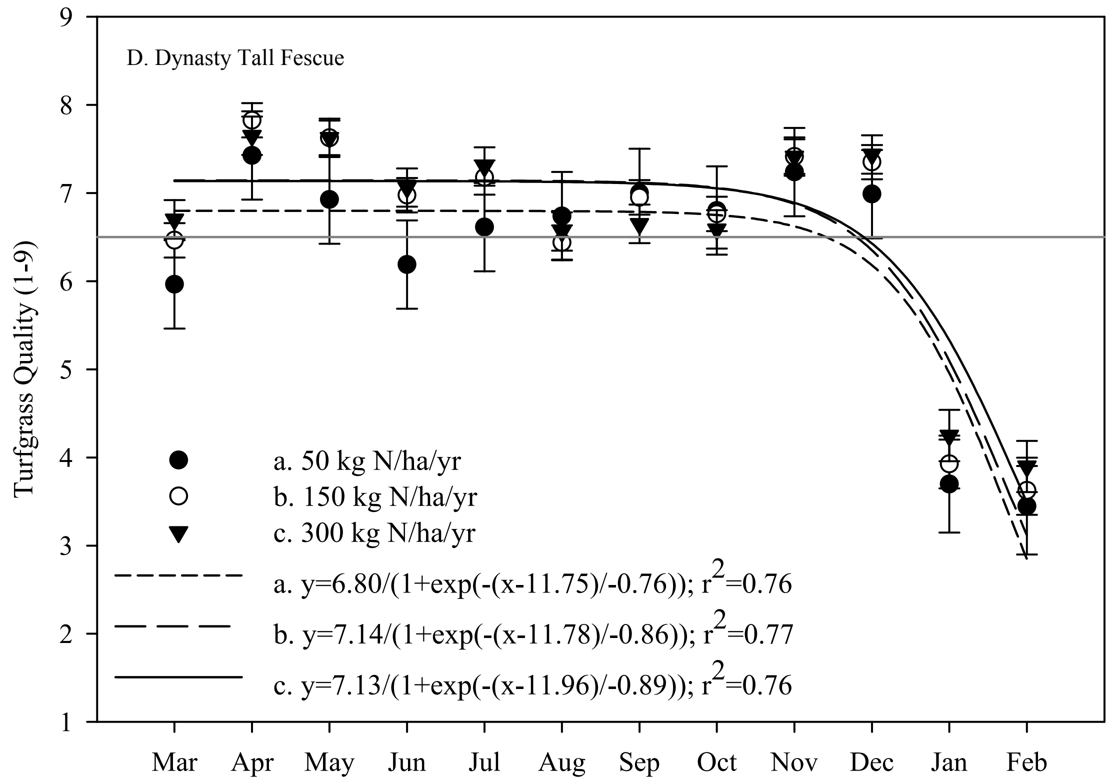

Figure 2. Continued.

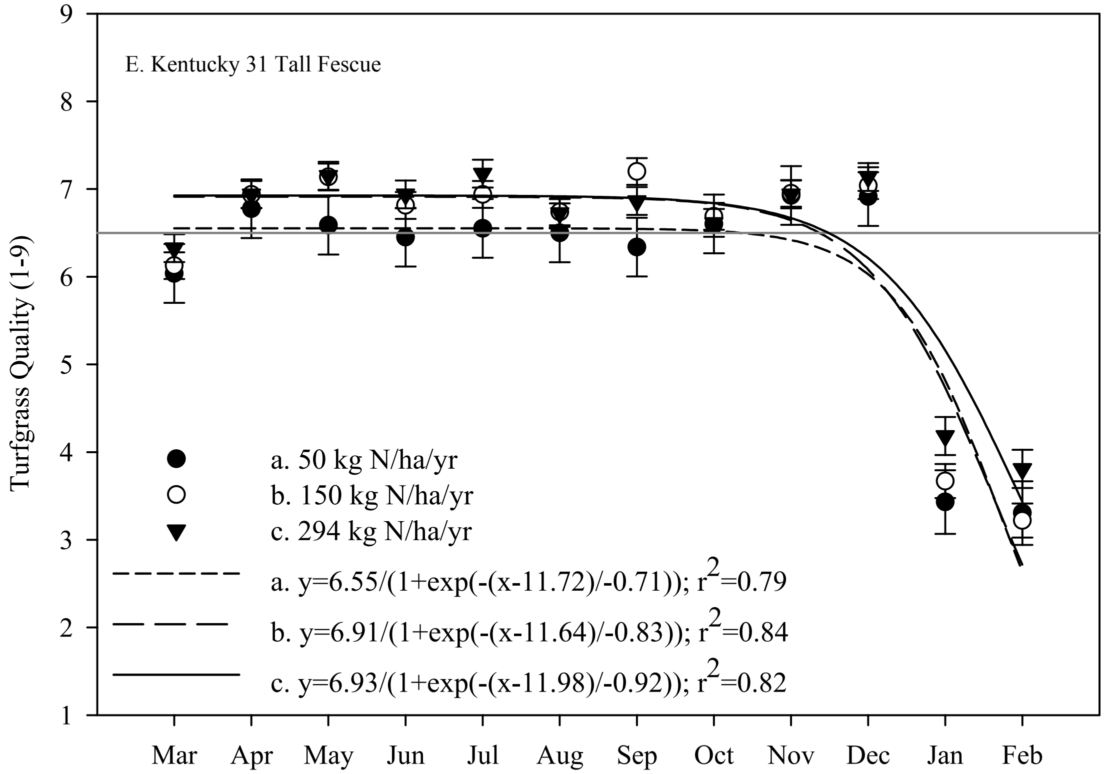

Figure 2. Continued.

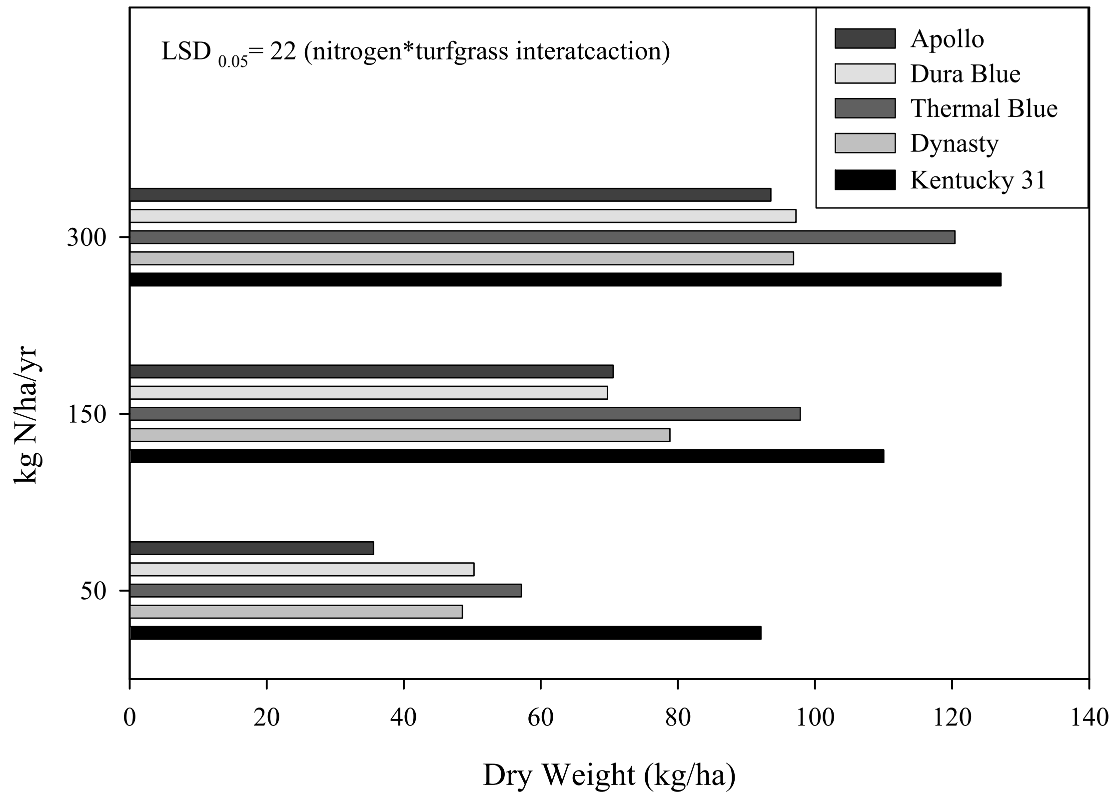

Figure 3. Dry weight analysis of Apollo, Dura Blue, Thermal Blue, Dynasty, and Kentucky 31 at 50, 150, and 300 kg N/ha/yr.

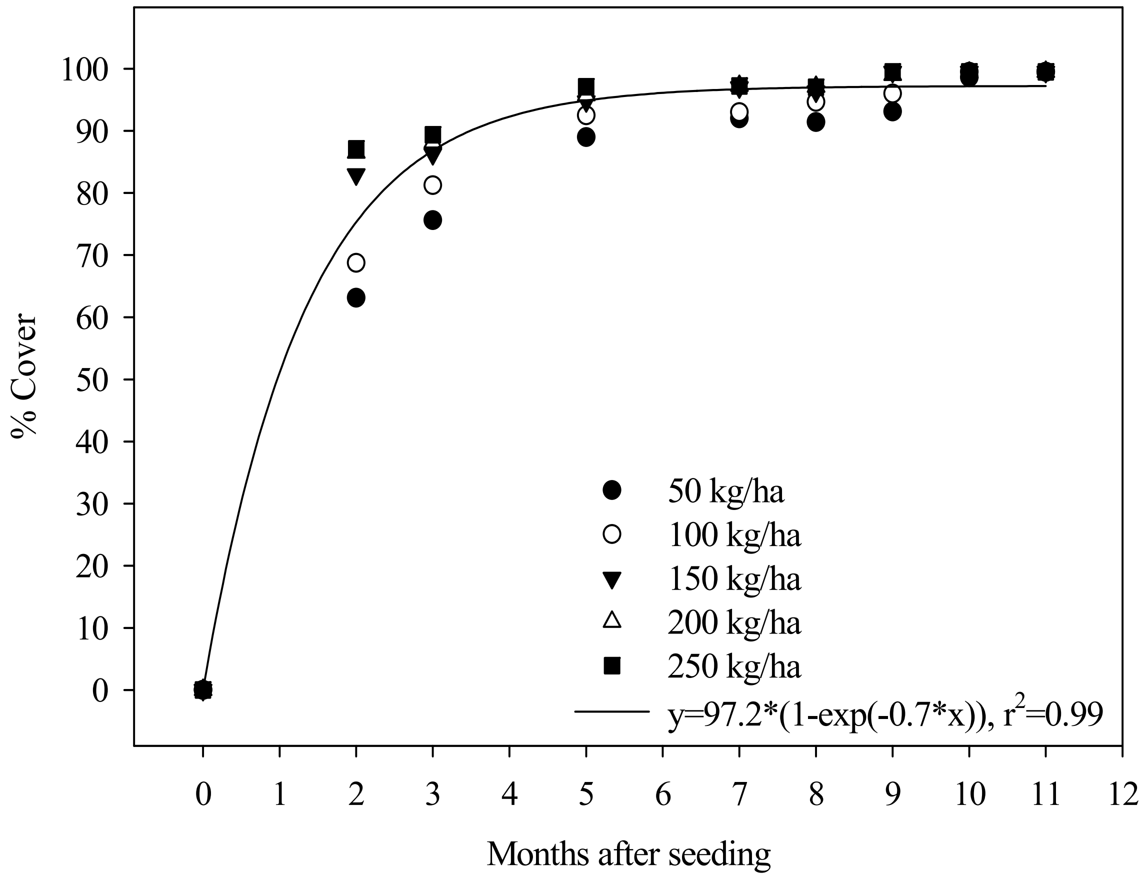

Figure 4. Thermal Blue cover using seeding rates from 50 to 250 kg/ha in Knoxville, TN in 2003 and 2004. Regression line represents an average of all rates pooled.

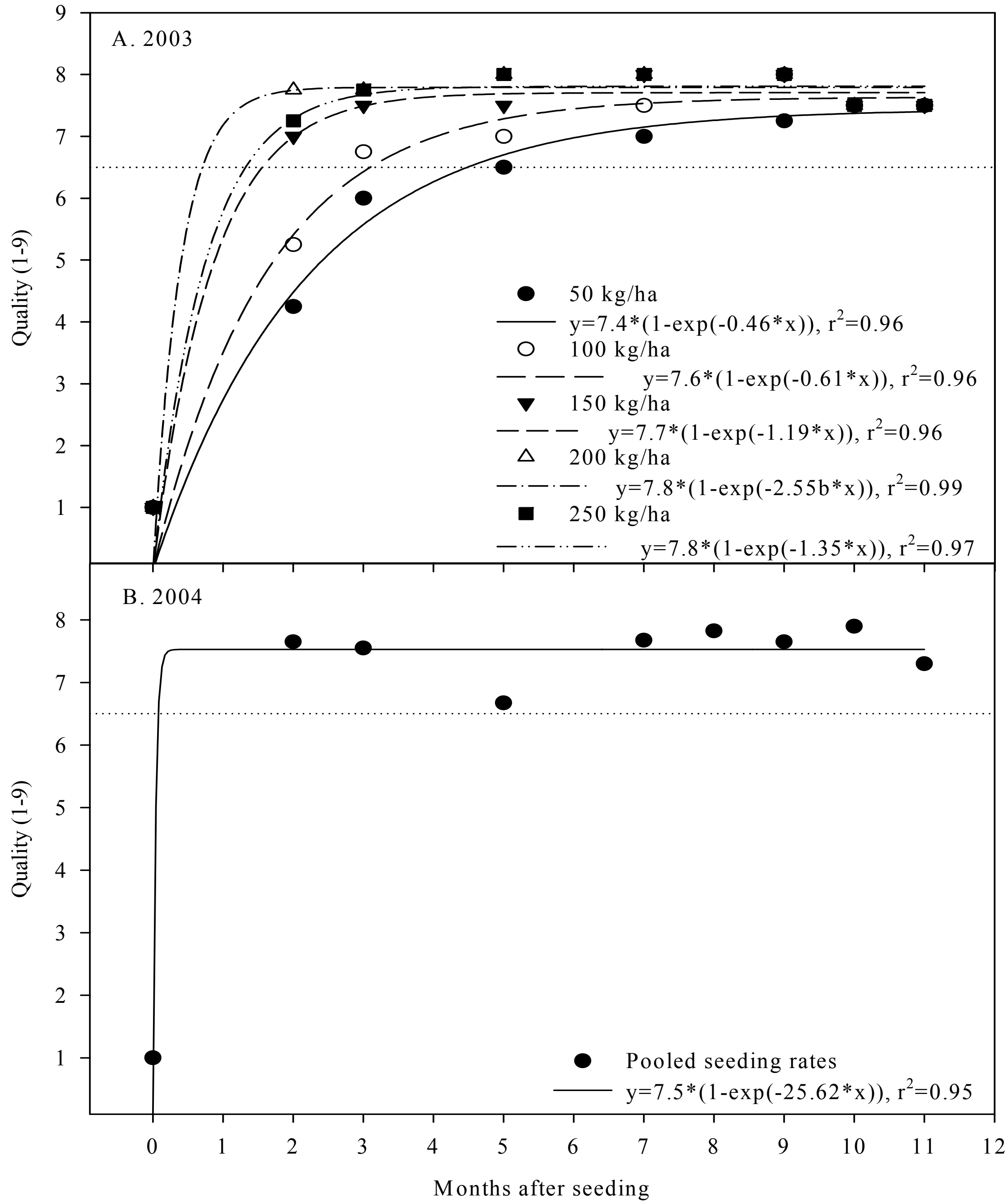

Figure 5. Thermal Blue quality using seeding rates from 50 to 250 kg/ha in Knoxville, TN in 2003 and 2004.

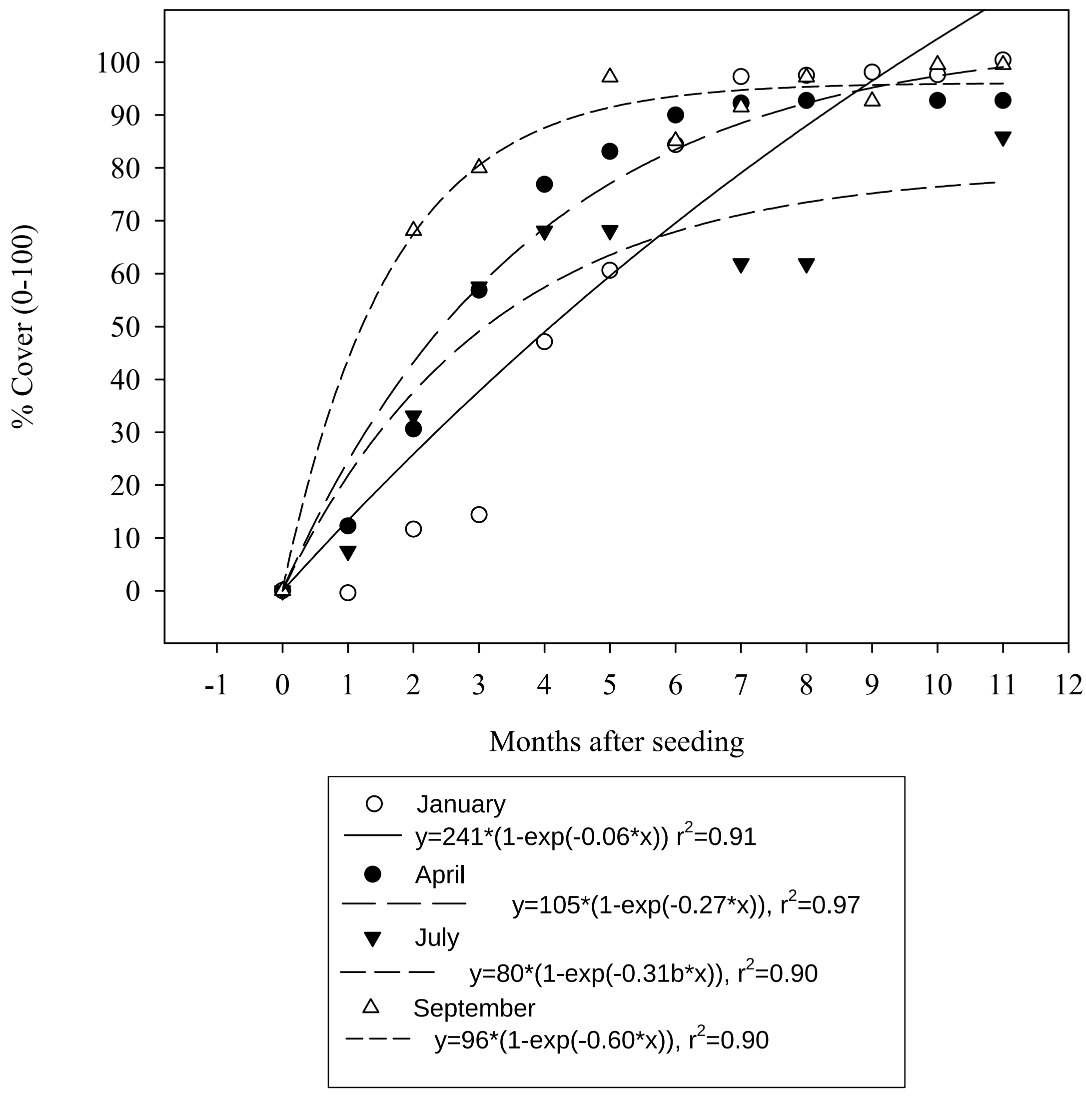

Figure 6. Thermal Blue cover when planted in January, April, July and September in Knoxville, TN in 2003 to 2005.

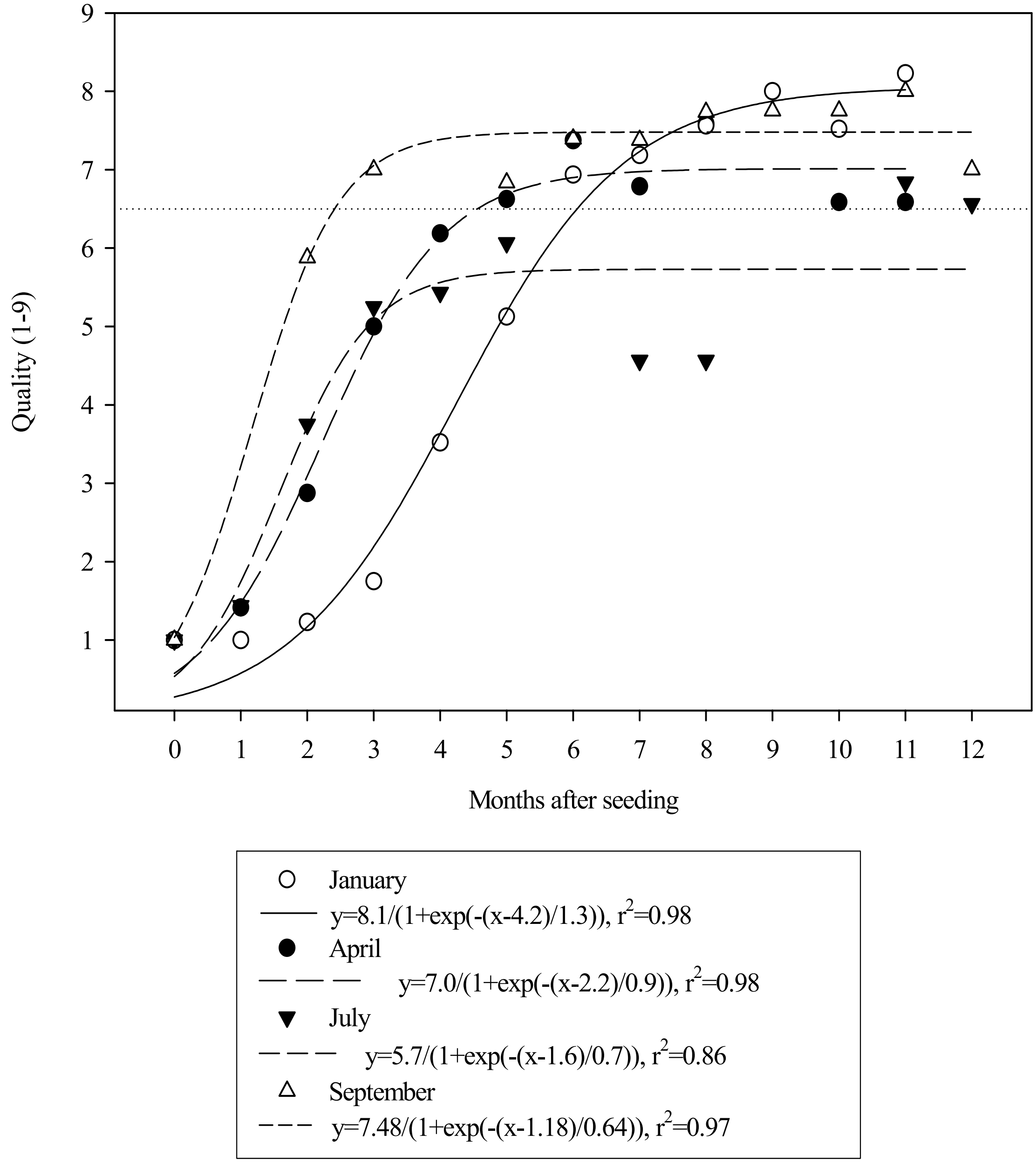

Figure 7. Thermal Blue quality when planted in January, April, July, and September in Knoxville, TN in 2003 to 2005.

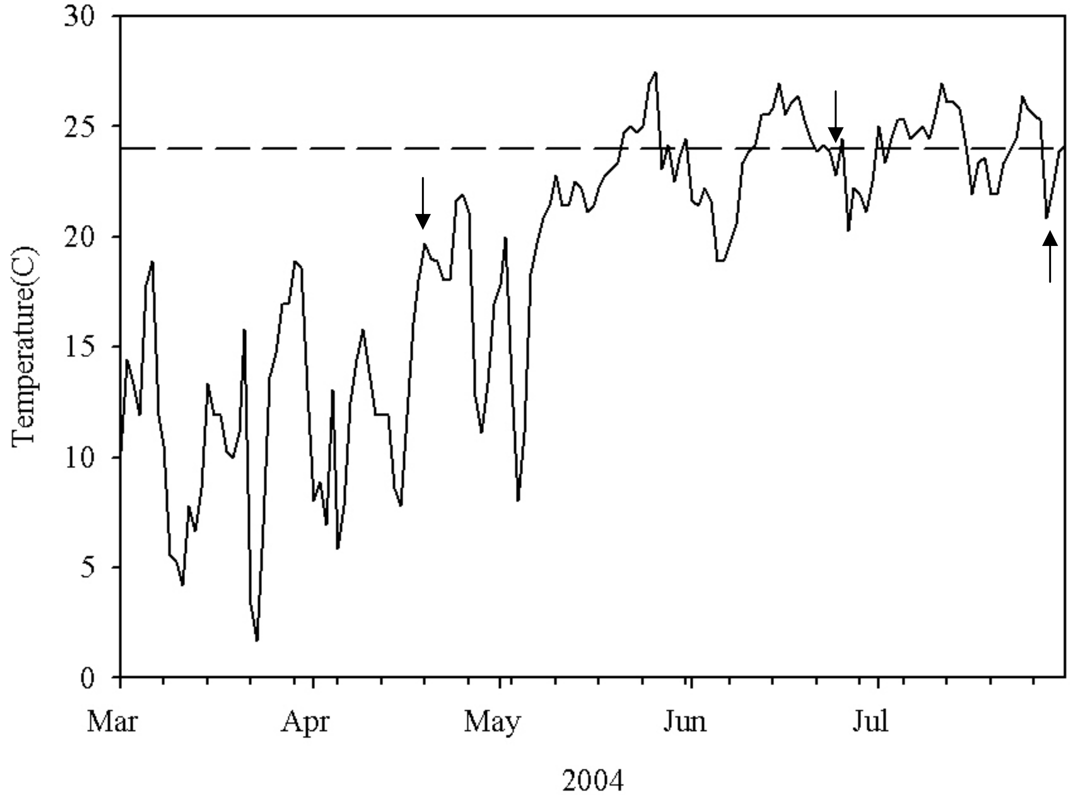

Figure 8. Average temperature at 2 locations from March 1 to July 31 in Knoxville, TN in 2004. Dashed line represents the maximum optimal growth temperature (Beard 1973) and arrows represent the April 20, June 24, and July 28 sampling dates.

VITA

Travis Charles Teuton was born in Ocala, Florida, on June 8, 1974. He was reared on a family farm in Anthony, Florida. He attended North Marion High School where he received his high school diploma in 1992. He attended Central Florida Community College where he received his Associate of Arts degree in 1996. He then attended the University of Florida where he received his Bachelor of Science specializing in turfgrass science in 1998. Upon graduation, he worked for Ocala Palms Golf Club as an assistant golf professional, assistant superintendent, and superintendent of grounds maintenance until 1999. He then worked for ProSource One as a golf course chemical and fertilizer sales representative until 2000. In the spring of 2002, he married Jennifer Ketchum and has two sons, Dakota and Cory Ketchum. He received his Master of Science degree at the University of Florida in 2002. He is currently at the University of Tennessee where he is pursuing his PhD in turfgrass science. Upon finishing his dissertation Travis will start at the University of Missouri-Columbia working as a research/teaching faculty in the area of turfgrass science.